PUBLIC WORKS MINISTRY.

IRRIGATION

IN

THE VALLEY OF THE RIVER PO

NORTHERN ITALY.

BEING AN ACCOUNT OF A MISSION UNDERTAKEN IN THE SUMMER OF 1899 FOR THE EGYPTIAN GOVERNMENT

BY

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CAIRO:

NATIONAL PRINTING DEPARTMENT,

1902.

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INTRODUCTION.

After working for six years as Inspector of Irrigation in the most difficult part of Egypt—the Delta proper—I was selected at the beginning of 1899, by Sir William Garstin, Under Secretary of State, Ministry of Public Works, to make out the Projects connected with the Storage Reservoir, now under construction at First Cataract, for converting into perennial lands the extensive tract of 320,000 acres in Middle Egypt at present under basin system.

Being entitled to three months' leave, which I intended to spend in Europe, I thought it profitable for my new work to visit, while I was there, some of the more important irrigation works, especially those of Northern Italy, the irrigation in which I had been told is most highly developed. But fearing that by going unofficially to a foreign country I should not be able to obtain so easily all the information that I desired, I solicited and obtained from the Government the favor of being sent to that country on mission. Many thanks are due from me to Sir W. Garstin and also to Mr. A. L. Webb, Inspector General of Irrigation in Upper Egypt, to both of whom I am indebted for the application made by the Ministry of Public Works to the Council of Ministers that I should be deputed "to visit and report upon the irrigation and reclamation works in the Po Valley."

Accordingly, on the 27th July, I left Alexandria on board the "Umberto I," of the Florio Rubatino s.s. Company, having been provided with a letter of introduction obtained for me by Sir W. Garstin from the Italian Consul General to the Minister of Foreign Affairs at Rome, who was asked to put me in communication with the irrigation

authorities. Moreover, before I left Cairo, Mr. Cavaliere Sola, of the Italian Agency at Cairo, and Mr. Colucci of our Ministry of Public Works, were kind enough to give me letters of introduction to their friends in Italy, and many thanks are due to these gentlemen, as these letters proved very useful.

The "Umberto I" reached Naples on the morning of the 31st July; but owing to the existence of the plague in Egypt, we were kept six days in quarantine, on board, near the Nisida Lazareth.

On the 6th August we landed at Naples. There I spent three days during which I visited the monuments and the environs of the town, and on the 9th I left for Rome.

On the 10th August I went to the "Consulta" to present my letter of introduction to the Minister of Foreign Affairs. I found his Excellency absent from Rome; but the Under Secretary of State, his Excellency M. Guido Fusinato, was present, and so I handed the letter over to him, and I find myself unable to express adequately my thanks to his Excellency for his hearty welcome and the many facilities he so kindly offered me for the easy fulfilment of my mission. He gave me letters of introduction to the Ministers of Public Works, of Finance, and of Agriculture, among whom the Irrigation Service is divided.[1] From the Minister of Public Works I obtained a circular to all the chief engineers in the Provinces of the Po Valley, requesting them to accompany me on their works, and to give such information as I might require.

In the absence of the Minister of Finance and also of the Minister of Agriculture, I called up on the Director General of the Domains, Commendatore Coli-Mazzoni, and the Director General of Agriculture, Commendatore Siemoni, both of whom were very kind in giving me letters of recommendation to the Domanial Canals' authorities in Piedmont and Lombardy, and also to the professors of hydraulics in the Agricultural Colleges of these provinces.

Besides all the letters of introduction that I have already mentioned,

[1] The Minister of Public Works has in his charge the management of the natural water-courses and the high control of the irrigation canals given in concession to private companies. The Minister of Finance has the management of certain canals made by the Government and called "Domanial Canals." The Minister of Agriculture has under his direction the Agricultural Colleges, the professors of which are often called on to give their opinion upon irrigation matters.

M. Fusinato most graciously gave me private letters of recommendation to the governors of the Milan and Turin Provinces.

While these letters were being prepared I seized the opportunity of my stay in Rome to visit its monuments, the quay walls on the Tiber, and the sewers alongside it which were then under construction.

This brought me to the 15th August, the day on which I left for Milan, the capital of Lombardy, where I arrived on the morning of the 16th. Soon after my arrival I paid a visit to M. Frigerio, Engineer of the Municipality, to whom I had a letter of introduction from M. Cavaliere Sola, of the Italian Agency at Cairo. During this visit I arranged with him to see, on the next day, the drainage works of the town, some of which were still in hand, and also the lands the irrigation of which is dependent on drainage water. On the morning of the 17th we started together and inspected carefully the works of two new sewers under construction. I noticed that these sewers were arched throughout their whole run through the town, but as soon as they emerge from the city they are left open. An interesting fact about those open parts is that they are, at intervals, crossed by road-bridges all made in cement concrete. From Mr. Frigerio I learned that a bridge of this kind, of 8·00 metres span and 3·00 metres roadway, and 4·00 metres height costs £E.40, and takes eight hours to build, and I believe that such a type of bridge might be adopted advantageously on our canals in Egypt.

On the 18th August I went with Mr. Frigerio to visit the Vettabia irrigation canal in the environs of Milan. This canal is the most ancient in Lombardy, as it was dug in the 12th century. It is fed partly from the drainage water, but principally from the water of the small streams of the Upper Milan, after being collected in the trenches of the ancient city. It was utilized for the first time by the monks of the Chiaravalle[1] at the close of the 12th century for the creation of the famous "Marcite," or winter meadows of Milan.

On the 19th August I saw the Chief Engineer of the Villoresi Canal,[2] the most recently dug in Lombardy. This gentleman was so

[1] A celebrated Abbey, situated a little to the south of Milan and founded in the 12th century by St. Bernard.

[2] The property of a private society.

busy that he could not then accompany me; but owing to the importance of this work, I decided to call on him again and arrange for a special visit to that canal.

On the 20th I called upon Mr. Spadon, Chief Engineer of the Province of Milan, in order to draw up with him a programme of my proposed visits to the canals and rivers that are under his direction.

On the 21st I visited, with Mr. Peribelli, District Engineer, the lower reach of the "Naviglio Grande," a branch of the river Ticino, terminating in the city of Milan in the "Darsena," or basin. On the same day I also visited the Canal of Pavia that flows from the "Darsena" and joins the Po river near the town of Pavia. On the 22nd I was accompanied by Mr. Toniolo, District Engineer, and we visited the Martezana Canal, which derives its water from the river Adda, and, like the "Naviglio Grande," terminates in the "Darsena." On the 23rd I went again with Mr. Peribelli to see the upper reach of the "Naviglio Grande" and the head works on the river Ticino.

On the 24th, I visited the Domanial Canal, "La Muzza," with the engineer in charge, Mr. Battaglia. This canal takes from the river Adda and tails into the Addeta which in turn tails into the Lambro, an affluent of the river Po. It is perhaps the largest canal in Italy, as it discharges 120 cubic metres per second or 10,368,000 cubic metres in twenty-four hours.

In my visits to the canals above named, I was struck with the praiseworthy state in which they are kept and by the care of the engineers in charge in distributing the water among the many branch canals by what they call "Modula." The canal banks are everywhere planted with trees regulary spaced. The lands commanded by the canals are very extensively cultivated, and rows of trees, either fruit trees or mulberry, are planted at almost regular distances in the fields.

On the 25th, I called upon M. Paladini, Professor of Hydraulics at the Polytechnic Institute of Milan. This gentleman is one of the highest authorities on this subject, and I had a long talk with him. A considerable part of the chapter devoted in this report to "Engineering Details" is the result of our meeting.

On the 26th August I went with M. Pasini, District Engineer, to a place called Regona, where a dangerous bend of the river Po exists. On our way I noticed how enormous were the banks of the river and how beautifully they were maintained. At some places I found the height of the banks to measure as much as 8 metres. At the bend the river has a width of about 400 metres, and is protected simply by stone revetment. No spurs whatever are used as with us in Egypt for Nile protection, and as far as I could judge from this particular place and from many other places near Ferrara, the method used in Italy is very efficient.

The 27th August was Sunday, and I spent it in reviewing and revising my notes. The following day I went to Legnano, a place situated to the north of Milan, at a distance of 1½ hours by rail. At this place there exist large workshops belonging to the Tosi family, for manufacturing steam and hydraulic engines. M. Boner, their Director, showed me over all these workshops, where I saw a large number of machines of the Sulzer type under construction intended for South America, as well as a large number of turbines. M. Boner was so kind as to present me with various plans and documents relating to pumping stations.

On the 29th August I left for Turin to arrange with the Director, M. Turina, for visits to the Cavour Canal, which is the most important in Piedmont. This canal derives its water from the river Po. I met this gentleman on 30th August and drew up with him a programme of my proposed visits. On the 31st, I went by rail to Chiavasso to meet M. Canavotto, engineer in charge of the head works, whom, having been previously informed of my intended visit, I found waiting for me in the station. He took me at once to the head works, where I was greatly struck by the grandeur of the head sluices of the canal, composed of twenty-one openings of 1·50 metres span surmounted by a magnificent building containing the regulating apparatus. Adjacent to this work is an escape on to the Po composed of nine openings having the same form and dimensions as those of the head sluice. There also I saw a temporary dam in dry rubble built across the Po, to hold up the water for the Cavour Canal, and it seems a great pity that

such an important canal[1] should be dependent on a temporary work. M. Canavotto, however, told me that the original project provided for a masonry dam, but owing to lack of funds it had never been executed. From the head works we drove along the canal for 10 kilometres, when we reached a very fine masonry aqueduct carrying the water of the Cavour Canal over the Dora Baltea, an important affluent of the Po. Continuing our progress we saw at kilometre 12, from our starting point, the tail of a feeder to the Cavour Canal. This feeder derives its waters from the Dora Baltea, and I was told that it insures to the Cavour Canal two-thirds of its discharge, while one-third only is taken from the river Po during low water season. From this point we went along by the feeder till we reaced its head which is as magnificent as the head of the Cavour Canal itself. Directly afterwards we went to a place called Cigliano, where I saw a very ingenious arrangement for lifting water to a height of 42 metres, from which a platèau having an area of about 3,500 acres is irrigated. From this point we returned to Chivasso, where I arranged with M. Canavotto to meet him another day at Santhia station so that I might continue my inspection of the canal; then I went back to Turin. During this first visit I had many opportunities of seeing the types of sluices, syphons, etc., adopted in Piedmont, and I much admire the readiness with which the water is directed to the desired point.

On the 1st September I went to see M. Turina in his office and asked him to kindly put at my disposal the plans of the various works I had seen the previous day, and to permit me to take a copy of what I judged to be of the most importance. He was kind enough to allow me to do this; moreover, he ordered his draughtsman to assist me, and also gave me an interesting publication on the work of the canal.

On the 2nd September I went by rail to Santhia. There I met M. Canavotto, who showed me an important hydrometric station yet under construction. It is built on the Ivrea Canal, a branch of the Dora Baltea, taking at a point situated further upstream than the off-take of the Cavour Canal feeder mentioned above. The object of this

[1] It has a total discharge of 80 cubic metres per second, and a length of 82 kilometres, exclusive of its numerous branches.

station is to enable the engineers to make experiments on water discharges on a larger scale than has yet been done in any part of the world. Having taken sufficient notes about this station we drove along the Ivrea Canal till we reached a place where it meets the Cavour at its 33rd kilometre. At this point the Ivrea Canal passes under the Cavour by a syphon to irrigate part of the land on the right side of the Cavour Canal. There I also saw a feeder to the Cavour made last summer from the Ivrea. I saw that the Ivrea Canal had been enlarged in its upper part so as to take the surplus water of the Depretis (or Cigliano) Canal, another branch of the Dora Baltea. We continued our journey along the Cavour Canal till we reached a place where it crosses the Sesia river, a very large tributary of the Po. On my way I saw many important works, such as syphons of all dimensions, head sluices of branch canals, escapes and road-bridges in masonry, sketches of nearly all of which I made. From there we went to Vercelli, and on our way saw very extensive fields under rice crops. At Vercelli I was introduced by M. Canavotto to M. Locarni, Secretary of the Society of Irrigation of the Lands to the west of the Sesia. This important Company is formed by the landlords of about 107,000 acres, the irrigation of which is dependent on the Cavour Canal. M. Locarni kindly accompanied me on the fields to show me some of their branch canals and gave me documents and maps concerning the company's work. After this, M. Canavotto and myself took leave of this gentleman and went by rail to Novara, where we spent the night. On the morning of the 3rd September M. Canavotto returned to Chivasso, and I went with M. Gattico, Resident Engineer, to see the last branches of the Cavour Canal and its tail into the river Ticino; in the evening I returned to Milan.

On the 4th of September I met M. Schiavoni, Chief Engineer of the Villoresi Canal, and had a long talk with him. I learned that this canal had been made between the Ticino and the Adda rivers in order to irrigate the high lands[1] that could not be irrigated neither by the "naviglio Grande" or by the Martesana Canal. While I was with him he telegraphed to his assistant, M. Salmoiraghi, requesting him to

[1] About 150,000 acres.

meet me the next day at the head works, so that he might accompany me on the canal and give me the necessary information concerning it. The following day I took the train to the station of Somma Lombarda. From there, after a carriage drive of 5 kilometres, I reached the head of the canal, where I found M. Salmoiraghi awaiting my arrival. With him I visited the head works on the river Ticino, the head sluice of the Villoresi Canal, and the heads of other channels that existed before the construction of the Villoresi. I saw also the head of a new canal,[1] not yet completed, which is intended, after it has run a distance of 6 kilometres, to pour its waters into the Ticino again, creating at its tail[2] a head of 28 metres. The Ticino in the reach between the head of this canal and Vizzola passes several rapids.

After having visited the head works and taken various notes and sketches, I followed with M. Salamoiraghi the course of the canal till we reached Vizzola, noting and sketching by the way the most important works that we passed. There, at the tail of the Industrial Canal I saw under construction a station of ten large turbines, two of which are reserve. These turbines, with a head of 28 metres and a total discharge of 50 cubic metres per second, will produce a force equivalent to 14,000 horse power, which is intented to be transformed into electric energy and transmitted to different villages at distances not exceeding 10 kilometres for producing electric light and to supply motive power to local industries. From Vizzola we still followed the Villoresi Canal till we reached the head of the "Arconate" distributary, and then we travelled along this distributary down to "Magenta" station, noting by the way the village channels and masonry works for water distribution. There I took leave of M. Salamoiraghi and returned to Milan.

On the 6th September I went with M. Frigerio, of the Municipality of Milan, to see the "Naviglio di Paderno," an old navigable channel[3] having six locks distributed on its whole length. It takes from the Adda at Paderno and tails into it 6 kilometres further downstream. The first kilometre of this canal has been recently enlarged and a new

[1] Known under the name of the Industrial Canal.

[2] Close to the village of Vizzola.

[3] This canal was made for navigation purposes, the Adda flowing alongside it being not navigable.

canal branches off at the end of the enlarged part. This branch passes by a tunnel under the hill that runs along the right side of the Adda, and after flowing underground for a distance of 5 kilometres, it issues from the hill, creating a head of 28 metres which, by means of eight turbines, two of which are reserve absorbing 45 cubic metres of water per second, produces a force of 12,000 horse power. This force is afterwards transformed into electric energy and transmitted to a maximum distance of 14 kilometres. Of these 12,000 horse power, 10,000 are employed for the electric lighting of Milan, for its tramways, and for the carrying on of some of its smaller industries, while the remaining 2,000 are used in the town of Monza, the Royal residence in summer.

While I am on the subject of force produced by water I must say that in nearly all the canals I have seen, the inhabitants have taken advantage of the heads created at the regulators and, in some cases, of the great velocity of the current, and have erected water-wheels or turbines for working factories of all sorts. I have taken full information about these engines, as I believe they can very advantageously replace the old wooden wheels used in our Fayoum Province.

Here I may note that the well-known wealth of Piedmont and Lombardy is certainly due to the proper canalisation of their rivers for irrigation, and for the production of force.

The 7th September I remained in Milan completing the copies of plans of the works that I had visited, and in the morning of the 8th I left for Ferrara, where I arrived in the evening. Although the whole country from Milan to Ferrara is full of interesting works, yet I did not stop on the way, as I understood from Professor Palidini and other authorities that these works were very similar to those I had already visited. Moreover, I was anxious to see the reclamation works carried out in the neighbourhood of Ferrara before the time assigned to my mission should expire.

Soon after my arrival at Ferrara, M. Stefani, Chief Engineer of the Province, who happened to know of my arrival, came to see me at the hotel, and we arranged to go the next day to inspect some important protection works on the river Reno, a few kilometers from Ferrara.

Accordingly, on the morning of the 9th September, we went by carriage to a place on the Reno river called Zena Vecchia, where a breach took place during the flood of 1897. The Reno, which looks more like an artificial channel than like a river, is nearly a straight stream, 100 metres wide, almost without berms, running between two enormous banks from 11 to 12 metres above country level, 5 metres wide at top and 80 metres[1] at bottom. I saw the breach of 1897 and also the works that were carried out to have it closed. The protection works against flood that I saw here are almost the same as those seen on the Po in Lombardy. After this visit we returned to Ferrara, where in the evening, we had a meeting with M. Giuseppe Borsari, the highest authority on land reclamation now in Italy, and with M. Cucchini, Chief Engineer of the important reclamation works of the Burana, an estate of not less than 200,000 acres running along the right bank of the Po, at some distance to the west of Ferrara. At this meeting I arranged for the visits that I intended to make to the different reclamation works in the Province of Ferrara and also in the neighbouring provinces.

On the 10th September we saw the main drain of Burana which serves at the same time as an important navigable canal connecting this estate with Ferrara and the Adriatic Sea, and I have noted all interesting works on this canal, such as inlets of private drains, locks, regulators, road-bridges, etc. The same day I visited also the reclamation works of the "Calare" estate, which is under the direction of M. Arrivabene as resident engineer, and M. Borsari as adviser. This estate is drained by a pumping station erected on the main drain of the Burana near Marozzo village, and after visiting this station we made our way to Codigaro, a village situated on the same main drain, where we spent the night.

On the 11th September we visited the reclamation works of Codigaro, an important estate of 127,000 acres lying on the drain of Burana and, like the Calare estate, drained by a huge pumping station erected on the above-mentioned main drain. After this visit we returned to Ferrara and on our way saw eight small estates, all drained by machines

[1] This figure includes the widths of the banquettes made to the banks on land side.

erected on the "Valli di Comachio"[1] or on channels leading to it. These eight estates are directly under the control of M. Borsari.

On the morning of the 12th September, Messrs Stefani, Cucchini, Gioppi, District Engineer, and myself went together to Bondeno, one hour distant by rail from Ferrara. There we visited in detail the important reclamation works directed by M. Cucchini, and returned to Ferrara in the evening of the same day.

Having the notes and sketches taken about the reclamation works I had visited up to this time, the Lamone colmatage works visited on the 14th September, and the various writings and plans most graciously presented to me by Messrs Stefani, Borsari, and Cucchini, I am going to devote a special chapter to these subjects.

All the reclamation works I had seen up to that time were made in view of draining the subsoil and the rain-water only, and upon my asking M. Stefani to show me some reclamation works by colmatage he said that none of the sort existed in his province, but a very successful colmatage existed in the Province of Ravenna. On that I asked him to telegraph to the chief engineer of that province to meet me on the 14th September at the Ravenna station in order that he might show me those works.

On the 13th September I went with M. Stefani to a place on the Po, near Ferrara, called Ponte Lagoscuro. There I visited some protection works and saw a revetment in rubble masonry with cement-mortar which answered very well.

On the morning of the 14th I went by rail to Ravenna and there I found M. Tordini, Chief Engineer, waiting for me at the station. He at once led me to the reclamation works of the estate known under the name of "Il Lamone." This estate, which was formerly all under water, measures about 20,000 acres. A torrent, called "Il Lamone," flowing down from the Appennine mountains, has been directed on to this land for the last thirty years, and the rich waters[2] which it pours in the flood time of each year did the colmatage up to now to the greater part of this tract. These works are treated in detail in the

[1] A lake situated on the shore of the Adriatic to the south of the main drain of Burana.
[2] Eight in 1000 of the volume of this water is a fertilizing solid material in suspension.

chapter devoted to "Reclamation works." After this visit I returned to Ferrara in the evening of the same day.

During my stay at Ferrara, M. Borsari advised me to go to Venice and visit the Neville workshops where the greater part of the pumping machines which I saw was made. Acting in accordance with his advice I left for Venice on the morning of the 15th September and it was not until the evening that I arrived at the island city. The following day I visited the Neville workshops, being shown through them by their director M. Bas. There I saw a large number of turbines and a number of centrifugal pumps under construction. M. Bas kindly gave me much valuable information about these machines and presented me with plans of execution of some of the pumping stations I had seen in the Province of Ferrara.

The evening of the same day I took the train for Milan, where I arrived late at night. On the 17th September I paid visits to the engineers, who had been so kind to me during my stay at Milan, to bid them good-bye and to receive from them certain drawings they had promised to prepare for me. On the morning of the 18th I left Milan for Geneva to take a short rest before my return to Egypt.

Thus a little over a month had been taken up by my tour in Northern Italy from my arrival at Milan on the 16th August till I left it definitely on 18th September.

From the many notes and sketches I took on my visits to the different works, the writings and plans kindly presented to me by the engineers with whom I came in contact, the hydrographic maps, and the different publications of the Ministries of Agriculture and Public Works graciously given to me, I have formed the present report which for convenience I have divided as follows:—

PART I.

CHAPTER I.—*General Remarks on the Valley of the River Po.*

" II.—*River Embankments and Protection Works against Flood in the Po Valley.*

" III.—*General Remarks on the Irrigation Works in the Po Valley.*

" IV.—*Irrigation in Piedmont.*

PART II.

CHAPTER V.—*Irrigation in Lombardy.*

" VI.—*Reclamation Works in the Delta of the Po.*

" VII.—*Cultivation in the Po Valley.*

" VIII.—*Engineering Details.*

Before closing this introduction I must add that much valuable information has been gathered from the following works:—

(1) "Italian Irrigation," by Captain Baird Smith (late Colonel Baird Smith), London, 1855.

(2) "Irrigation in Southern Europe," by Lieutenant C. C. Scott Moncrief (now Colonel Sir Colin), London, 1868.

(3) "Des Canaux d'Irrigation de l'Italie Septentrionale," by Nadault de Buffon, Paris, 1861.

(4) "Les Irrigations," by A. Ronna, Paris, 1889.

(5) "Report (in Dutch), on the Irrigation in Northern Italy and Spain," by Grinwis Plaat Gedrukt, ter Algemenne, 1895.

In writing this report, I have endeavoured to deserve the confidence placed in me by my chiefs, and I humbly beg them to excuse the defects they will find in my style, as I am sure they will find many. My good intentions and limited knowledge of the English language will, I feel sure, recommend me to their indulgence.

ISMAIL SIRRY.

Minia, 13th November, 1899.

PART I.

CHAPTER I.

General Remarks on the Valley of the River Po.

1.—Description of the River Po and its Valley.

The river Po originates at Monviso in the Re plateau, whose altitude is 1,952 metres above the sea. From this point it follows a north-easterly direction till it reaches the city of Turin, then it strikes to the east and keeps almost this direction till it reaches the Adriatic Sea. Before this it divides into several branches[1] constituting between them the Delta of the river, and finally falls into the Adriatic.

The length of the course of the Po from its source till it pours into the sea is 652 kilometres. This length is more than one and a half times the direct distance between Monviso and the Adriatic, which is about 420 kilometres.

The length of the valley in which the river runs is about 520 kilometres and its breadth may attain 220 kilometres.

The great importance of the river is due more to the extent of its catchment basin than to its length. Up to Ponte-Lagoscuro the area of this basin is 69,382 sq. kilometres, of which 41,056 are mountainous and 28,326 in the plain.

By the Po Valley is ordinarily meant the extensive basin lying between the Alps and the Appenines, the former extending from Cadibona Neck to the Julian Alps for a length of 1,572 kilometres and the latter from the same neck to the Moon Alps for a length of about 390 kilometres. This basin has a gentle slope at the east portion and expands to the great Gulf of Venice, where it has a coast-line of nearly 250 kilometres.

[1] The actual principal branches are—The Po di Pila, that of Tollo, of Maestra, of Gnocco and of Goro.

The basin proper of the Po does not effectively include the whole of that large valley, but is limited on the north by the river Adige and the Canal Bianco basin and on the south by the course of the Volano river, which is now converted into a main drain for the Burana estate situated in the neighbourhood of the city of Ferrara.

The bed of the Po does not follow the middle of the valley but tends to the south against the Appenines, being subject to the greater power of the Alpine affluents in comparison with the power of those of the Appenines, since the confluents push the recipient in a direction opposite to their own course.

2.—Affluents of the Po.

Numerous affluents come down from the Alps and Appenines, bringing to the Po their tribute of water in more or less copious quantities. Among the principal affluents we may mention here the Ticino, the Tanaro, the Dora Baltea, the Sesia, the Adda, the Oglio and the Mincio.

3.—Regions and Provinces crossed by the Po.

In its long course the Po touches upon or crosses the Provinces of Cuneo, Turin, Novara, Alessandria, Pavia, Piacenza, Milan, Cremona, Parma, Reggio, Mantua, Ferrara and Rovigo, distributing the materials brought down from the sides of the mountains. These materials vary in size from one extreme to the other—from the rocky blocks spread on the slopes of the mountains to the silt of the littoral where the river ends.

Geographically and historically the Po Valley is divided among Piedmont, Lombardy Venitia and Emilia.

Piedmont, the most westerly situated division of the four, is bounded on three sides by the Alps and the Appenines, and terminates at the river Ticino on the Lombardy boundary.

It comprises at present the provinces of Turin, Novara, Cuneo and Alessandria, and has an area of 29,349 sq. kilometres.

Lombardy, situated between the Alps and river Po, is separated from Piedmont by the river Ticino, as mentioned above, and from Venitia by the river Mincio. It is composed of eight provinces: Como, Milan, Pavia, Sondrio, Bergamo, Cremona, Brescia and Mantua, and has a total area of 23,507 sq. kilometres.

To the east of the Mincio and to the north of the Po comes Venitia, comprising the provinces of Verona, Vicenza, Padua, Rovigo, Venice,

Treviso, Belluno, and Udine and having an area of 23,464 sq. kilometres.

The remaining part of the valley to the south of the Po is occupied by Emilia, comprising eight provinces, viz., Piacenza, Parma Reggio, Modena, Bologna, Ferrara, Ravenna, and Forli, and measuring 20,515 sq. kilometres.

4.—Means of the Distribution of the Fertilizing Water of the Po.

From the enormous quantity of fertilizing matter carried by its water the Po has been called the Nile of Italy. In order that such a river may be really profitable it is necessary that its water and fertile alluvium be spread on the irrigable land instead of being lost in the sea.

The Cavour Canal utilizes on the left plain the alluvium of the upper valley terminating at Chiavasso, and the Casale Canal gives to the land the fertilizing matter picked up by the Po between Chiavasso and Casale.

Downstream of Casale, studies had been made for canals to take from below the confluents of the Tanaro and the Ticino, but until now no steps have been taken towards their execution, and the Po continues to receive between its two banks and to bury in the Adriatic the inestimable riches that the water carries away from the vast and fertile territories comprising the basin proper of the river.

5.—Solid Matter contained in the Po Water.

The quantity of solid matter carried away by the Po into the sea is about 40 million cubic metres per annum. The left tributaries of the Po, those which come down from the Alps, not only bring to the Po the greater part of the supply of water but most of its solid matter. The southern bare rocky slopes of the Alps, exposed to the action of the sun and to the damp south winds, oppose to these winds a strong resistance, causing the fall of rain which carries with it great quantities of dust, sand, gravel, and stone to the rapid mountain streams. The silt of the Po, which as we said comes from this, amounts on an average to 0·000788; or dry measured to 0·00026 and in flood to $\frac{1}{300}$.

It is no wonder, therefore, that with the above quantities of slime the bed of the Po has risen and the river has divided near its mouth into several branches, forming a delta which is itself continually advancing into the sea. This extension of the delta renders the making

of banks necessary to protect the land recovered from the sea. In the lower part of the Po Valley the high water level of the river is about 5·00 metres above the adjacent country, and its normal level is from 2 to 3. On the 23rd October, 1872, a breach took place in the embankment of the Po, innudating the town of Ferrara, where the height of water in the streets reached 4·00 metres. To give an idea of the rapidity of extension of the Po Delta I may quote the following instances. The town of Ravenna was in the Middle Ages a seaport, it is now situated 8 kilometres from the sea. 2,000 years ago the town of Adria was on the sea; in the 12th century it was situated at 9·32 kilometres from the sea, in the 16th century at 18·58 kilometres, and in 1840 at 33·39 kilometres. For the three periods the yearly advance of the coast was therefore respectively 7·8 metres, 23·1 metres, 61·7 metres.

6.—Discharge of the Po.

According to Lombardini the maximum discharge of the Po is about 7,000 cubic metres per second, the minimum 200 cubic metres, and the mean discharge 1,720 cubic metres.

7.—Slopes of the Po and its Tributaries.

The slope of the Po towards the Adriatic and that of the right and left tributaries towards the Po, gives to the plain two corresponding declivities, variable from upstream to downstream according to the regions, being always greater in the direction of the breadth than it is in the direction of the length of the valley.

The following table gives water surface slopes of the Po:—

Places.	W.S.L. above sea.	Slope per kilometre.	Velocity in metres.
Origine	1950	47·00	—
Revello	350	1·80	—
Turin	207	0·58	1·80
Ticino mouth	56	0·35	—
Lambro	—	0·24	—
Adda	31	0·15	—
Secchia	—	0·13	—
Pontelagoseuro	5	0·06	—
Mouth of river	0	—	—

The following table gives the slope of the principal tributaries of the Po:—

Right Bank.	Left Bank.	Length in kilometres.	Slope per kilometre in metres.
—	Dora Riparia	110	—
—	Dora Baltea	150	—
—	Sesia...	130	—
Tanaro...	—	170	—
—	Ticino	220	1·695
Trebbia	—	90	—
—	Adda...	280	1·538
Tara	—	100	—
Enza	—	90	—
—	Oglio...	250	1·389
—	Mincio	200	0·934
Secchia	—	140	—
Panaro	—	140	—

8.—Nature of the Soil in the Po Valley.

The nature of the soil is variable according to its origin, which is either the Apennine ridge or that of the Alps, and also according to the character of the affluent rivers that cross the different zones.

In Piedmont, the soil on the right side of the Po is generally compact and the marly element prevails, whereas on the left side the soil is softer and also stony on account of the predominance of siliceous elements and sandstone. On the high plain on the left side, layers fairly compact are also met with at the mouths of the valleys of the following affluents of the Po, viz., Dora Riparia, Stura, Orco, Dora Baltea, and Sesia. Also very soft layers of porphyritic sand are met with in the lower zone between the affluents Agogna and Ticino.

In Lombardy the soil is similar in its general character to that of Piedmont already described. In the upper portions of the plains it consists of deep beds of gravel overlaid by light sand, and wells sunk in it to a depth exceeding 100 metres show the same uniform section. In the lower portions there are considerable areas of clayey soil underlaid, however, as before, by a subsoil of pervious gravel or sand, through which the water finds its way with facility. The only great marsh in the country is in the vicinity of Crema, between the Adda and the Serio (a small affluent of the Po). Throughout the whole province of Mantua the soil is heavy and compact, necessitating the use of

drainage as extensively as that of irrigation. In a word the irrigated region is a great alluvial plain exhibiting the usual varieties of surface soil found in such formations, and enriched by an abundance of manure caused by the large quantities of cattle which form the principal element of its prosperity.

In Venitia I mention only the province of Rovigo which touches the Po. This province is formed of a long tract of land comprised between the left bank of the Po and the right bank of the river Adige. It begins from the boundary of the Mantua and Verona provinces and extends as far as the Adriatic Sea into which all the water of this province is drained. The soil is of alluvial formation, and on account of its peculiar situation the most important thing is not irrigation but drainage. The territory is divided into thirty-three "Consortii" for the drainage.

In Emilia four provinces are touched by the Po, viz., Piacenza, Parma, Ferrara, and Ravenna. The soil in the province of Piacenza is generally clayey or calcareous in the high zones. In this province there is a lack of perennial water, irrigation water being derived from torrents. There is, however, a zone of small extent where springs exist at small depth. It is the eastern zone of the province and extends from Chiavenna to Ongina.

In the province of Parma the soil is clayey or marly with little permeable subsoil. This province is also deprived of perennial water, irrigation water being derived from torrents coming down from the Appenines. Very small is the water-logged area; there is only some land in the neighbourhood of the town of Parma of this nature. In the commons of Cortile San Martino and San Lazzaro, artesian wells have been sunk between the torrents Parma and Enza, giving in all 0·170 cubic metres of water per second, which is used for domestic and irrigation purposes.

In the Province of Ferrara the soil and the subsoil are formed of an exceedingly clayey land which is so impregnated with water that the level of the springs is very near the surface. For this reason, no irrigation, properly speaking, is carried on in this province—all engineering works executed are for drainage.

The Ferrara plain is the product of the continual struggle between the land and the rivers and between these and the sea. It extends from the Burana estate to the sea, on a length which extends 100 kilometres. The country level varies from 6 to 10 metres above the sea.

The province of Ravenna is similar to that of Ferrara. The soil is more or less clayey or siliceous. No irrigation, properly speaking, is

done. The great aim of the people is drainage. In this province, to the north of the town of Ravenna, is situated the Lamone estate in which the most successful reclamation works with muddy water that exist in Italy are carried on.

9.—Hydrography of the Po Valley.

The high development which the irrigation has given to the agriculture in the Po Valley is admirable. This finds its explanation in the favourable climatic and the hydrographic situation of the land.

The irrigation here assists the crops to resist the great heat and the long periods of drought in summer. Besides, scarcely anywhere else in the world is such a quantity of water so easily within the reach of the agriculturist as here. In the Po Valley, and especially in Lombardy, the drought gives but little anxiety to the cultivators, as in many places spring water can be easily brought to the surface of the ground. The small water-courses coming down from the Alps run rapidly to the Po and its big affluents, and in a certain measure they pay a satisfactory tribute to the agriculture. In spite of the incessant civil and foreign wars in times past, the agriculture was highly developed. Thus in the 13th century the monks of Chiaravalli raised irrigation to the standard of an art and created the celebrated "Marcite" or winter meadows.

10.—Rain and Rainfall.

The annual rainfall in the Po Valley is certainly considerable. The hot southern and south-eastern winds of the Sahara become saturated with vapour in passing over the sea, and on coming in contact with the snowy and lofty summits of the Alps, they cool and thus the vapour is condensed and rainfall is caused just at the place where the affluents of the Po take their source. For this reason, the rainfall upon the southern slopes of the Alps and the adjacent Po Valley is greater than that upon the northern slopes. But in South Tyrol the winds first blow against the Ortler and Trienter Alps and are robbed of their moisture; the fact that the rainfall is less in South than in North Tyrol is an exception.

Owing to the configuration of the Appenines the rainfall in the eastern part of the Po Valley is greater than in the western part. This chain becomes lower and lower as one goes eastward and conse-

quently opposes less resistence to the winds in their eastern part than in the western.

The following figures giving the annual rainfalls registered at different stations confirm the preceding statements:—

(a) *North of the Alps:—*

North Tyrol	1·108
North Carinthia	1·068
Styria	0·938

(b) *South of the Alps:—*

South Switzerland	1·560
South Tyrol	0·938
South Carinthia	1·639
Frioul	1·865
Piedmont	1·068
Lombardy Valley	1·055
Venice Valley	1·109
Coast Land	1·430

We see from the above figures that the rainfall just to the south of the Alps, excepting South Tyrol, is the highest, and that the rainfall increases from west to east. These figures show also how considerable is the rainfall in the Po Valley as compared with the more northerly situated countries, such for example, as Holland, where the annual rainfall is 0·65 metres, and Northern Germany, where it is from 0·40 metres to 0·55 metres.

The figures relating to the Po Valley may be very well compared with the rainfall in the region of Victoria Nyanza and Albert Nyanza in Central Africa, where the annual fall of rain is about 1·50 metres.

From May to August, when the temperature is the highest and the soil in the greatest need of water, the rainfall at Milan and Turin is 331·6 millimetres and 333·2 millimetres respectively, and the rainy days are respectively 38·0 and 34·8.

11.—Periods of Drought.

The longer or shorter duration of the periods of drought determine the necessity for, and value of, irrigation. Professor Palidini, of the Polytechnical College of Milan—from official observations made in the years 1882 to 1886—has drawn up the following statement:—

STATIONS.	Level above sea.	1st quarter.		2nd quarter.		3rd quarter.		4th quarter.	
		N	*n*	N	*n*	N	*n*	N	*n*
Turin	275	48	25	16	12	20	17	45	25
Alessandria...	98	43	25	16	12	17	15	28	22
Milan	147	30	19	24	15	16	14	47	22
Verona... ...	66	40	26	21	15	16	14	28	20
Venice... ...	21	39	25	15	12	26	17	43	21
Parma... ...	89	23	17	10	9·5	27	18	25	16
Modena.. ...	64	21	17	18	10	30	19	24	20
Naples... ...	149	21	16	24	20	48	28	21	15
Palermo. ...	72	22	16	66	34	44	33	22	13

where N and n are respectively the maximum and mean durations of the longest period of drought.

12.—Loss sustained by Agriculture from Drought.

From the above statement it will be seen that even the mean durations of the longest periods of drought are too long for the crops.

Professor Paladini gives the following formula to find the loss sustained by agriculture from drought:—

$$D = 70 \left[\frac{N}{N_d}\right]^2 \frac{1 - 0{\cdot}01\,(2n - N)}{n}$$

where

- D — Percentage decrease of the gross yield.
- N and n — The figures given in the foregoing statement for the 2nd and 3rd quarters, when the water is the most needed.
- N_d — A coefficient variable with the kind of crops. It has the following values:—

CROPS.	2nd quarter.	3rd quarter.
Lemon, Orange, Olive	N_d 46	N_d 37
Cereals	„ 30	„ 20
Legume	„ 24	„ 16
Grass land	„ 18	„ 14
Vegetables	„ 12	„ 10

These figures relate to unirrigated sandy and calcareous lands; for clayey and damp lands the cœfficient N_d should be increased by $\frac{1}{10}$.

3.—Rainfall at different Places.

Professor Paladini has also established a formula for finding the rainfall at a given place when the rainfall at another place situated in the same hydrological basin is known. This formula is—

$$H_p = H_s + f\ (\Delta h,\ \Delta l,\ \Delta d),$$

where

- H The amount of rainfall.
- Δd The change in the elevation going from S to P.
- Δl The change in the distance to sea going from S to P.
- Δd The change in the distance of highest crest of water separation.

For the region of the Alps and the tributary valley this formula becomes—

$$H_p = H_s - 0{\cdot}01\ [0{\cdot}1\ (\Delta h + \Delta l) + 0{\cdot}85\ \Delta d]\,;$$

where, Δh is in metres, Δl and Δd in kilometres. This formula is only applicable when $\Delta h < 300$, $\Delta l < 100$ and $\Delta d < 100$.

The following table has been drawn up by applying this last formula:—

PLACES P.	PLACES S.	H_s	Δh	Δl	Δd	H_p Calculated.	H_p Observed.
Domodossola... ...	Milan ...	1·000	147	74	−94	1·580	1·420
Novara	,,	,,	21	36	−23	1·138	1·045
Pavia	,,	,,	−49	−5	37	0·739	0·757
Piacenza..	,,	,,	−75	−49	40	0·784	0·734
Brescia	,,	,,	25	−86	41	0·941	0·975
Bergamo..	,,	,,	135	−37	−35	1·200	1·290
Como	,,	,,	65	—	−32	1·207	1·319
Alessandria	,,	,,	−49	39	27	0·780	1·668
Mondovi...	Turin ...	0·896	281	13	−35	0·856	0·876
Casale Monferrato.	,,	,,	−154	−59	23	0·844	0·834
Alessandria	,,	,,	−177	−71	58	0·581	0·668
Novara	,,	,,	−107	−74	8	0·939	1·045
Biella	Chioggia..	0·930	11	—	−19	1·100	0·789
Padua	,,	,,	21	36	−30	1·128	0·861
Vicenza...	,,	,,	46	61	−43	1·183	1·159
Udine	,,	,,	106	34	116	1·676	1·551

The same formula gives also good results for the Appenine region, provided that the places to be considered are not remotely situated or placed in extraordinarily hilly regions, thus:

Places P.	Places S.	H_s	Δh	Δl	Δd	H_p	
						Calculated.	Observed.
Parma	Modena...	0·716	25	45	2	0·629	0·634
Parma	Reggio ...	0·808	27	26	−8	0·698	0·634
Pisa...	Livorno...	0·872	−14	10	−16	1·012	0·967
Siena	Grosseto..	0·669	317	60	−60	0·799	0·784
Perugia...	Rome ...	0·760	470	−85	−70	0·960	1·022
Cosenza...	Catanzaro	0·970	−87	42	−21	1·100	1·202

14.—Lakes existing in the Po Valley and their Emissaries.

We see from the foregoing how considerable the rainfall is and how regularly distributed the rain-water is, and consequently how the land of the Po Valley is favoured by nature. The wealth of the inhabitants of this valley is increased by the thorough distribution of the water of its rivers by means of artificial canals, and also by the regular slope of its lands which, without extraordinary expenditure, make irrigation possible.

In other countries less favourably situated, the flood water is, with great expense, stored in artificial reservoirs for watering the crops in periods of drought, whereas the glaciers and snow of the Alps, and the lakes situated at the foot of this chain insure to the Po Valley a regular supply of water for irrigation. Unfortunately, much of this water, as already stated, flows down into the Po and thence into the sea without giving any profit to the agriculture.

The following table, which contains many valuable "data," gives a fair idea of the importance of these lakes:—

Name of Lake.	Length	Breadth	Maximum Depth.	Area	Contour	Level above Sea.	Water Level. Highest	Water Level. Lowest	Catchment Basin	Emissaries of Lakes or Defluents.	Flowing in	Discharge of the Emissaries or Defluents. Minim.	Mean.	Maxim.
	Kilom.	Kilom.		Sq. Kil.	Kilom.		Metres.	Metres.	Sq. Kilom.			Cubic Metres.	Cubic Metres.	Cubic Metres.
		(1)					+	—		(2)	(2)			
Lingano or Ceresio ...	35·00	3·00 *m* 1·05 *a*	279·00	48·00	87·50	270·50	2·56	0·05	540·00	R. Tresa	L. Maggiore... ...	9·58	—	152·50
Varese	8·50	3·07 *m* 1·05 *a*	26·00	14·60	21·25	235·60	—	—	66·40	C. Bardello	„	1·20	2·70	12·00
Biandrono	1·26	0·38 *a*	4·70	0·834	—	238·00	—	—		C. della Valle ...	C. Bardello	—	0·03	—
Comabbio	4·73	1·59 *m*	7·70	3·80	9·13	240·00	—	—	24·50	C. Borghi	L. Varese	—	0·50	—
Monate	8·00	1·00 *a*	34·10	2·10	—	264·00	—	—	15·00	C. Acquanegra ...	L. Maggiore... ...	—	0·30	—
Delio	—	—	—	0·20	—	970·00	—	—	2·00	R. Giona	„	—	0·03	—
Ghirla	1·25	0·34 *m*	—	0·29	—	—	—	—	15·00	C. Margorabbia ...	R. Tresa	—	0·20	—
Mergozzo	2·30	1·00 *a*	80·00	2·10	—	194·65	—	—	—	R. Toce...	L. Maggire	—	—	—
Orta...	13·00	2·00 *m*	250·00	16·00	—	290·00	—	—	125·00	C. Nigolgia ... R. Strona ...	R. Toce...	1·10	3·00	—
Maggiore or Verbano ...	65·00	1·275 to 4·60	372·00	214·00	166·75	192·65	6·94	0·57	6·200	R. Ticino	R. Po	59·00	313·00	4940·00
Como or Lario	48·00	1·5 to 4·0	588·00	156·00	—	196·04	3·95	0·44	3880·	R. Adda	„	18·00	181·00	827·00
Pusiano	—	—	30·00	—	—	259·20	—	—	—	R. Lambro	„	—	—	—
Iseo...	23·00	2·5 to 5·25	300·00	58·00	52·00	198·68	2·76	0·02	1915·	R. Oglio	„	20·00	75·00	320·00
Guarda or Benaco ...	49·00	6 to 15	584·00	362·00	—	64·07	2·17	0·00	2044·	R. Mincio	„	35·08	77·00	139·00

(1) *m* signifies maximum ; *a* mean. (2) R. signifies River ; C. Canal ; L. Lake.

It is evident that these lakes, which occupy a total area of 878 square kilometres, exercise the greatest favourable influence on the regular flowing of the rivers which derive their water from them, and are of an inestimable benefit to the irrigation. The cold water that comes from the glaciers into these lakes becomes therein warmed.

These lakes are also very useful as settling basins, and in spite of this fact they can continue for centuries to serve as storage reservoirs on account of their enormous capacity, the Lake Maggiore alone has a capacity of 34,632,168,250 cubic metres.

The principal emissaries of these lakes are the Ticino, the Adda, the Mincio and the Oglio the waters of which are used for irrigation and for the production of motive power. To show the character of these rivers I give the following table and formulæ:—

River Reach.	Slope per kilometre in metres.	Velocity in metres per sec.
Ticino:—		
From Sesto Calende to Tornavente	2·22	4·80
„ Tornavente to Boffalora	1·88	4·00
„ Boffalora to Gravellone	1·27	2·75
The Gravellone to the Po	0·30	0·65
Adda:—		
From Lecco to Paderno	1·22	2·46
„ Paderno to Martesana	1·47	3·09
„ Martesana to Vinzasca	0·57	1·85
„ Vinzasca to the Po	0·42	1·36
Mincio:—		
Average for the whole river	0·15	0·80

According to Pestalozza the discharge of the Tresa can be calculated out by the formula:—

$$D = 4{\cdot}47\ (4{\cdot}511 + a)\ (0{\cdot}45 + a)^{\frac{3}{2}} \sqrt{0{\cdot}98 + a}$$

where a is the water level at Ponte Tresa gauge.

According to Lombardini the discharge of the Adda is:—

$$D = 100\, a^{\frac{3}{2}}\ (1 - 0{\cdot}032\, a).$$

where a is the height of water over the bottom of the outlet of the lake situated about 0·50 metres below zero at the guage at Como.

In the work entitled, "Idrometria del Po," published by the Public Works Department in Italy, I found the following formula for the

calculation of the discharge of the Po with reference to gauge readings at Ponte-Lagoscuro, viz:—

$$D = 182.88\ (1.08 + a)$$

where a is the water level at Ponte-Lagoscuro gauge. The levels of water being measured from a point situated 6·00 metres below the zero of this guage.

Besides the emissaries of the lakes there are numbers of small affluents which originate in the valley, or in the Alps, and pour their water into the Po.

To bring the water from the Appenines to the Po there are large and small streams which, I dare say, prove without exception, useful for irrigation, but in general they are of less importance than those already mentioned and are not so well managed.

15.—Regime of the Rivers in the Po Valley.

All the above rivers may be classed under two great categories, both having well marked natural characteristics.

The first category comprises the rivers fed especially by the snow and by the springs existing in the slopes of their Pre-Alpine dales. The supply of these rivers is abundant in winter and spring from the melting of the snow; whereas in summer their supply is the lowest, as the snow has already disappeared from the action of the first heat and the spring rain.

The second category comprises the rivers that owe their supply more to the snow and ice that cover the high mountains and the remote recesses of their valleys, than to the snow and the Pre-Alpine springs.

These rivers, in contrast with the former, have their supply in spring and summer because of the intense and the late cold in the high valleys; the abundant supply in summer takes place constantly from the middle of May till September and becomes exuberant in the driest and most critical period of the season.

In the category of summer rivers are included the Dora Riparia, the Dora Baltea, the Ticino and the Adda.

The winter rivers have their alluvium clayo-ochreous, and the water has always a high temperature. Those of summer have more of a sandy and ashy alluvium and their water is cooler in summer than it is in winter, as appears from the following table of thermometric observations made simultaneously in the water of the Po and that of the Dora Baltea.

Temperature on the 21st to the 28th January, 1890, at 7.30 a.m.[1] :—

Dates.	Po at Chivasso.		Dora Baltea at Ivrea.	
	In open air, north.	Immersed in flowing water.	In open air, north.	Immersed in flowing water.
	°C	°C	°C	°C
21st January	0·00	0·05	−0·01	0·04
22nd "	0·01	0·05	0·03	0·03
23rd "	0·05	0·05	−0·01	0·04
24th "	0·15	0·05	0·08	0·03
25th "	0·00	0·05	−0·02	0·27
26th "	0·04	0·06	0·15	0·04
27th "	0·00	0·05	−0·37	0·03
28th "	−0·01	0·05	−0·04	0·30

The difference in the alluvium and in the temperature of the water of the rivers of the two categories depends on the condition of weather and place in which the water itself takes its source, whether from the cavities or from the slopes of the Alps, from snow and springs, or from glaciers.

The two categories complement each other and serve admirably to constitute a good regimen for irrigation.

For winter irrigation, the abundant supply of winter rivers is utilized and that of summer rivers is used for summer irrigation. The irrigation canals in Piedmont, especially, are so arranged that all the derivations from the river made to insure the supply can substitute or assist each other.

The clayey alluvium brought to the lands with irrigation water corrects the very soft soil with a slow but constant and sure reclaiming effect, while the sandy alluvium modifies the very tenacious soil.

The higher temperature and the abundant supply of the winter rivers favour, in winter, the culture of winter meadows, and contribute, in the spring, to the sowing of rice. The abundant and constant supply of the summer rivers from the middle of May to September insure the existence of all crops.

[1] The difference would appear better if observations could be made when temperature is lower. At 7° below zero, derivations of the Dora Baltea transport blocks of ice which travel in the canals throughout their whole length. This fact has never occurred in the derivations of the Po and Sesia, even at lower temperature.

CHAPTER II.

River Embankments and Defence Works against Inundation in the Po Valley.

1.—Banks; their Rôle and Structure.

(a) *Object of Banks.*—When a water-course, river, or torrent, coming down from a hilly valley or a high plain (which because of the high level is not subject to inundation) commences to run through alluvial land of more or less recent formation the level of which is commanded by flood water, this land needs to be protected by earthen banks by means of which the flood water is retained.

(b)—*Construction of Banks.*—The construction and maintenance of banks carry with them a large and various number of other works either to minimise the damages that the banks cause to the adjacent country by infiltration, etc., or to meet the changes that occur in the water-courses which sometimes render insufficient and improper those banks which were at first most convenient for the purpose for which they were made; and thus we can say that with the construction of banks a continual struggle is engaged in between the forces of man and those of nature.

The rivers and torrents carry with the water, stone, gravel, sand and silt. In the large plains that have to be protected by banks, big stones do not exist; in a few places gravel may be found, but in general sand and earth prevail in these plains.

The confinement of water between the banks creates in the river-beds slopes varying according to the different water-courses and the different localities in which they are made. It depends on the quantity of water flowing in the water-course, on the succession of droughts to floods, on the kind of the materials forming the sides of the mountains from which the water comes, and on the obstacles created by man for water derivations or water escaping, etc. Such confinement may also cause the advance of the mouth of the river into the sea and may render necessary the extension of the banks, on the main river and its affluents, further upstream, for the purpose of protecting from inundation new lands previously left subject to inundation, or for protecting lands which were

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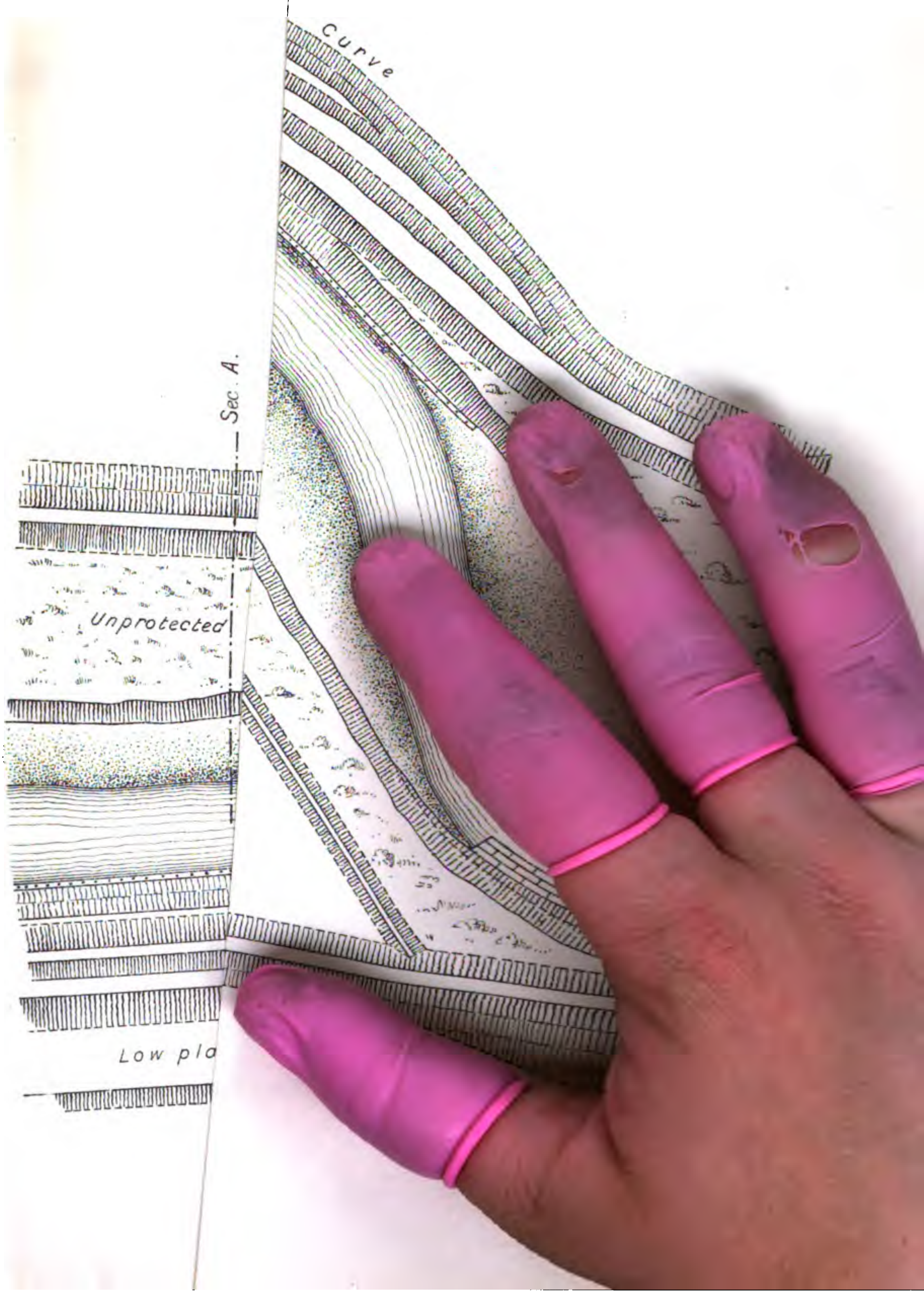

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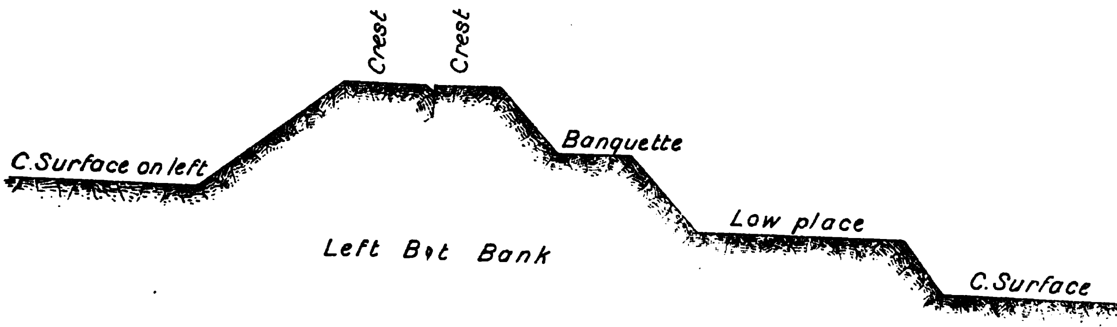

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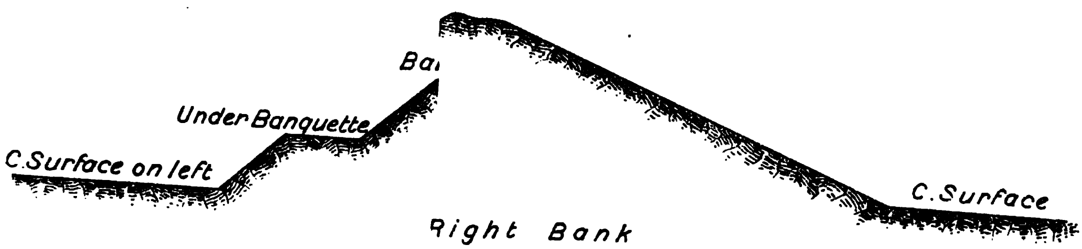


not formerly reached by flood-water but become so under the new circumstances.

For all these causes the beds of the rivers rise and consequently the flood level rises also, and the banks previously constructed become insufficient and subject to be surmounted by the flood-water and liable to be breached, causing to the adjacent country greater damages than those which would result from a natural overflow.

In consequence of the above facts, the banks need to be always modified by being raised and enlarged with brought earth, a common operation in all the embanked rivers. Banks which were originally made low, 3 to 4 metres high, for instance, have been afterwards raised to 8, 10 or even 12 metres on account of the rise of the river-bed above country level to the height of a man or even more, and in order to give to such banks sufficient strength, banquettes and under-banquettes have to be made and the low places behind them have to be filled up.

(c) *Form of Banks.*—The most usual form for the banks are shown on Plates II and III on which are noted the names of the different parts composing the banks or those having any connection with them.

In the construction of a bank it is necessary to examine the bed on which it is to stand, by means of wells and soundings, if need be. If the subsoil is composed of muddy layers of appreciable depth it will be necessary either to select another site or to make a large base to the bank. If also layers of pure sand are found at a small depth, it will be necessary to cut a trench either under the whole breadth of the embankment or at least under a certain portion of it and replace the sand by clay.

In all cases, the surface on which the bank is to be raised should be ploughed and cleared from all foreign materials.

For new banks it is convenient to select earth of a good quality, excluding that which is excessively sandy, as this kind of earth has no cohesion and requires to be sloped too gently; it is permeable and also easily eroded. The excessively clayey earth should also be avoided, because although it forms very solid banks when newly made, yet it is difficult to work and, moreover, it easily leaves pockets in the body of the banks. The magnesian or soapy earth should be absolutely rejected as it presents the same defects as the clayey earth, and, further, it becomes by the action of humidity so slippery that the form of the ridge can be maintained only with difficulty. It is subject to easy slip and always requires a very long slope.

In the construction of banks it is convenient to proceed by spreading layers of 0·20 to 0·30 metres thick, which should be watered and rammed.

In the case of joining a new bank to an old one, or in the case of strengthening an existing bank, or in adding a banquette to it, great precaution should be taken in joining the old to the new works. All grass and vegetation should be cut down and offsets in the old bank should be made at the joint with the new work. The new bank should be revetted with grass. It should not be exposed to current water till after the necessary time required for the settlement has elapsed and after the grass that revets it has grown.

(d) *Embankment in the Po Valley.*—A very good example of complete embankment is that of the river Po. It has continuous and unsubmergeable banks from the mouth of the Adda to the Adriatic, a length of more than 300 kilometres, exclusive of the numerous branches existing in its delta, embanked on a length of 95 kilometres, and of the different isolated parts in the upper provinces between the Sesia and the Adda on a length of 130 kilometres, making in all more than 525 kilometres as the total length of the embanked part of the river, or about two-thirds of its whole length.

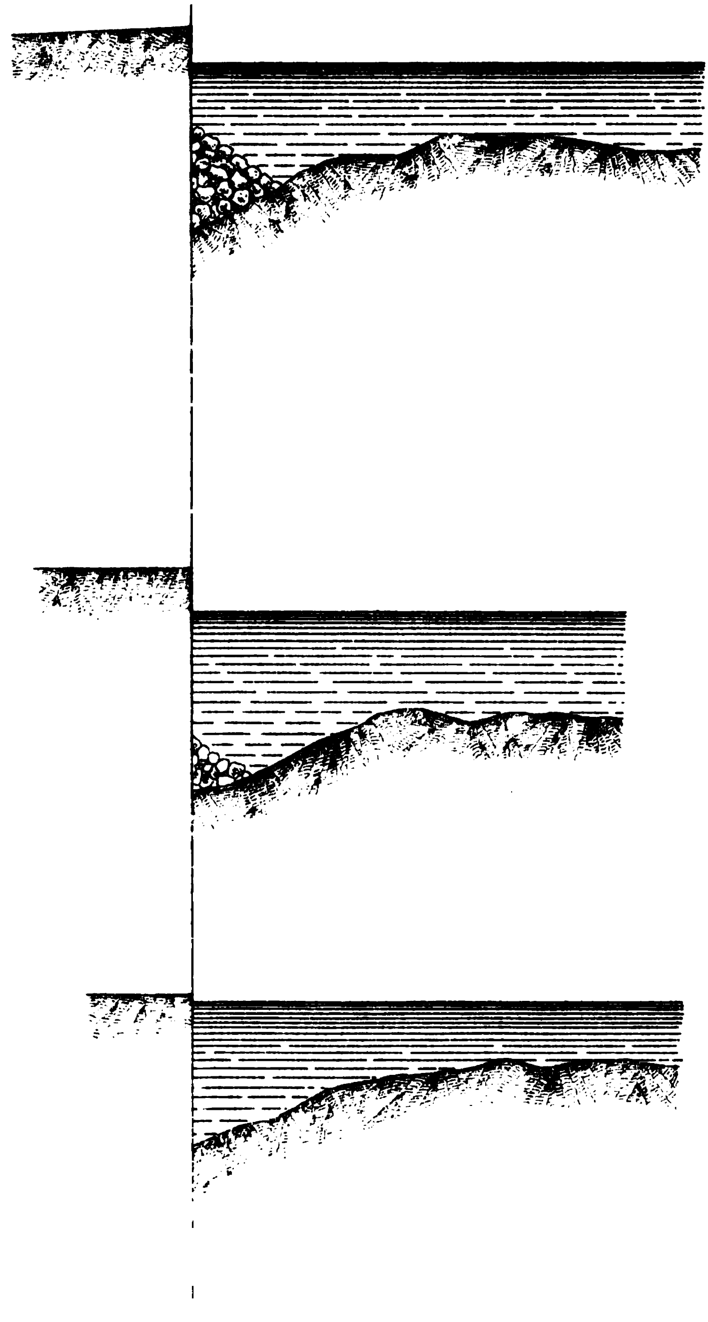
The origin of this system of defence, absolutely necessary for the existence and wealth of an immense plain of fertile and well cultivated lands, measuring about 7000 square kilometres, of which the gross revenue amounts to more than £E.7,500,000 per annum, and which are by this system alone protected from the devastating and persistent summer floods, goes back to the remotest antiquity. Without the embankment the Po Valley would be covered with isolated forests and unhealthy swamps.

2.—Defence Works of Banks.

(a) *Evils to which the Banks are exposed.*—The banks are exposed to erosion, to sinking, to slipping, to percolation, and to passage of water by syphoning, besides becoming insufficient for protecting the land from the river.

As to their insufficiency of protection, either because of the height or the breadth and form of banks, we have said enough in treating of bank construction, and so it is time to speak of the other evils to which the banks are exposed, reserving to add further on a few considerations on certain cases of insufficiency of bank dimensions in which the increase of size will not prove a sufficient remedy, and for which the best remedy is to colmatage the land behind the banks or to make a new tracing of the river with the redressing of the banks.

PL. V.



(b) *Defence against erosion.*—The erosion and internal sinking are almost always produced by eddies at the foot of the bank. The first, in rare cases and in a small measure, is produced by the action of the current water.

To prevent or to remedy such evils the following works are used: The "Piani di Rosta," made either from live "Piani" or dead "Piani," the "buzzonato," the "gabbionate," the green timber "mantellatura," the "sepioni tessuti" or "passaglioni," and the plantations "a boschetto." Besides the above the following works are also used: spurs, stone revetting, "volpastri" revetting, canvas covering or mat covering, "ciuffate," sacks full of earth, "palaffite," sustaining walls, revetting walls, and finally retiring banks if the condition of the river requires it or allows it. All these works are frequently associated.

The "pinnelli" or "repellenti" has been sometimes used and is still used, though rarely.

Before entering into the details of the above works we must remark here that the works in dry wood or that intended to dry, have the defect of being subject to rapid destruction. Those in live wood, although more lasting, have not long duration, as they are subject to damages by man and animals. They, moreover, favor silt deposit, and consequently are most objectionable for small water-courses which they are intended to detain, they alter the side slopes in rendering them too steep and subject to be detached and to slip; moreover, they require to be entirely renewed when they are worn as nothing of them remains useful for new work.

On the contrary, they are most useful in the case of large rivers running in localities where earth for making banks of big size with banquettes and under-banquettes, etc., is scarce, as the plantations "a boschetto" and the "passaglioni" encourage the silt deposit and consequently the formation of berms.

The rubble protection works are free from the defect of total destruction, because when a rubble revetment slips it forms a good footing for a new work which follows more economically and which will last longer than the first work. In general when a protective work in rubble stone has been exposed to the action of three or more high floods, when for two or three times it has given way and afterwards been restored, one can say that it has definitely become sound.

Below are described the defence works above-mentioned:—

(b_1) The "Piani di Rosta" are composed of wooden boards bound together and arranged in plan in a normal direction with the current. The thickness of each of these "Piani" is 0·30 metre and are formed

of two rows of stakes about 2 to 3 metres long and of poles bound at their ends in a manner like that of the rim of the basket. The process of protection works with the "Piani" consists in laying down the first "Piano" as above described, while above it a layer of earth 0·10 metre thick is thrown and over it a second "Piano" and a second layer of earth, etc. The different "Piani" should be disposed with a little drawback so as to form at the end, benches rising one above the other.

If the "Piani" are to be made below the water surface of the river, strong and dry wood (oak or elm) should be used, and in this case they are called "Piani Morti." If, on the contrary, they are to be placed above the ordinary water level, green wood (ordinarily willow) which is likely to grow should be used, and in this case they are called "Piani Vivi."

(b_2) The "buzzoni" consist of cylinders 2 to 3 metres long of about 0·40 metre diameter. Each cylinder is composed of a nucleus of hard earth or rubble stone enveloped in rice straw ; the whole is afterwards surrounded with a complete envelope of willow or poplar wood, strengthened by four poles of willow called "Costole." This done each "buzzone" should be fastened with 8 or 10 strong ligatures of willow branches placed at equal distances from each other.

Ordinarily, the "buzzoni" are used for filling in whirlpools, and consequently for giving a convenient slope to the sides of a channel. They are always sunk in the water parallel to the current. In rare cases they prove sufficient when thrown free, but in most cases they are tied, five by five, before they are sunk, and they are usually closed by wicker or covered by a jetty.

(b_3) The "Gabbioni" are cylinders generally 4 metres long and 0·80 diameter. They are formed from a tissue of wicker turned round nine poles of willow in the form of a basket. They are then filled with rubble and debris. The "gabbioni" are ordinarily arranged in a parallel line to the slope which they are meant to protect from slipping or erosion. This material costs much, and it is easily damaged and consequently it is very little used.

(d_4) On the contrary, the "burghi a calcestruzzo" which are no more than "gabbioni" disposed on the slope for the purpose of defence, normally with the current, have a good effect in some special cases. They are filled with cement, and when from their weight and the action of the water they sink down they are added to in such a way that their length may attain sometimes as much as 10 or 15 metres or even more.

(d_5) The "mantellature" consist of filling in the internal slope of a bank for protecting it against wave action or against erosion. If such revetment is made with prismatic slabs of grass, it is called "impellectura semplice," if it is made with paralleliped slabs, each one fastened to the slope of the bank by two or more pegs of green willow, it is called "mantellatura di Zolle." If the revetment is made with a boarding of green willow and fastened to the slope with different rows of poles in which stakes of green willow are interwoven, it is called "mantellatura di legna." If the force of the erosion of water is great the slope is then revetted with rubble stone, which is sometimes laid in a mortar of lime and sand, and in this case the revetment is called "mantellatura di sassi a secco od in calce." In urgent cases and for small lengths only, it is usual to revet the internal threatened slope, temporarily, with canvas or mats fixed with poles driven in the slope, taking care that the upstream border of each canvas is covered a little by the downstream border of the preceding one.

(d_6) The "volpastri" are parallelopipeds consisting of turf sods 0·40 metres long, 0·20 metres broad, and 0·10 metres thick, or of clayey and tenacious earth cut to these dimensions. They are re-covered with an envelope of rice straw fastened with two ties in cross or with two parallel ties and a third tie in cross, made with fresh cut osier or with ropes made of rice straw.

The "volpastri" are used ordinarily as refilling materials or for revetting a slope instead of the ordinary "mantellatura."

(d_7) The "palizzàte" are used for sustaining the slope of a bank tending to slip down. They are made by driving poles or needles fastened to each other and of proportional length to that of the slope which they are required to protect. Sometimes the poles, instead of being attached to one another, are, on the contrary, spaced from 0·40 to 0·50 metres from each other and tied with joists of oak held with iron nails; but in this case a boarding of wood is placed between the poles and the slope.

(d_8) The "passaglioni" or "sepioni tussuti" are especially noted for encouraging silt deposit along the banks in flood time. They are made by planting along the foot of the bank a hedge of willow branches, placed at short distances from each other, with which little branches of the same kind interlace. From this longitudinal line start other cross lines going towards the bank and made in the same way. The water finding a difficulty in its movement, its velocity decreases and the spaces existing between these wooden works are silted up.

(d_9) The plantations, "a boschetto," are formed from little branches

of green willow of very fresh cut which are arranged in rows parallel to the slope, the branches of each row alternating with those of the next. When the branches are inclined to the direction of the current they are called "schivardoni."

These works are used for inducing silt deposit.

(d_{10}) The rubble stone revetment is used mostly for protecting banks in case of the existence of deep whirlpools in front of them.

When the slope has a sufficiently regular surface which needs to be simply protected from possible erosion, the revetment is put directly on the slope with 1·50 metres thickness at least, raising it 1·00 or 2·00 metres above the ordinary water level. If on the contrary the slope is irregular, eroded, and has no regular inclination, using rubble exclusively will be too costly, and so in this case it will be more convenient to fill in the cavity with pebbles, which are less costly than rubble, or with "buzzoni," or also sometimes with "volpastri," afterwards covering these materials with rubble.

Ordinarly, a revetment is constructed from a nucleus of light material, as the "buzzoni," on which the rubble is put in such a way that, at one metre above low water level, it forms a banquette of a certain width having a long slope under water. Any subsidence caused to the revetment in flood time is easily repaired with pebbles.

In the places where big stones are scarce or too costly, they can be replaced by artificial blocks which are no more than concrete prisms in cement, variable in form and size according to the circumstances. "Buzzoni" formed with pebbles of small size placed in wire netting can be used for the same purpose. Such "buzzoni" are most convenient in the present case as they are flexible and of various forms.

If during flood any slips in the internal slope of a bank take place the following material is used to meet such evil.

(d_{11}) The "ciuffate" consist of trees to which sacks of earth are attached. They are submerged in the water with their branches turned down, and they are kept in place by means of ropes attached to pegs driven in the body of the bank.

In the upper reaches of water-courses where the slope is great and water carries with it gravel and pebbles, the usual defence work of wood and other materials or, even, the rubble revetment are not sufficient. In such cases expensive retaining walls are constructed. These walls require deep foundations and proportionate thickness.

(d_{12}) The "penello" or "repellente" is a solid work that extends obliquely from a fixed point on the slope of a river and enters into the bed, thus serving as an obstacle to the flood current and forcing it to

change its direction towards the oppòsite slope. The "penelli" can be made of masonry, of big wood, of "gabbioni," or of fascines of wood alternating with layers of earth as in the "piani di rosta."

The "penelli" of masonry can seldom be applied to the beds of the embanked water-courses, but are preferable in mountainous parts where the beds present large quantities of stones. They consist of walls of proportionate length, height, and thickness which must have sloping top.

The "penelli" in wood consist of strong "palaffite" covered above water with joists. Those of "gabbioni" are formed by throwing in a quantity of "gabbioni" over which other "gabbioni" are regularly placed in such a way as to obtain a solid body having the form and size required.

It is useful and sometimes necessary to carry back a certain length of a bank which is wanted to be conserved. This is produced by a work called "scarico."

(d_{13}) "Scarico."—This work is done by cutting the inequalities produced on the front slope by erosion, dressing this slope and strengthening the banks at the same time with the earth cut from the front by raising it or enlarging it if the top is at a sufficiently high level. If the earth cut off the front is not sufficient the balance can be got from the adjacent land. Instances of defence works especially visited by me are shown on Plates .

3.—Defence Works from Slipping, Sinking, and Passage of Water.

The slippings take place in the inner or outer slope because of the bad quality of the earth from which the bank is formed. This is the case when the earth used is devoid of quartzy elements and is eminently clayey or of a pure sand incapable of any cohesion. The best remedy for meeting such an evil is, if possible, to change the earth by knocking down, in great part, the existing bank on the outer side and then reconstructing it from good earth. When it cannot be so done it is necessary to give a long slope to the bank which should be revetted with turf sods.

The sinkings are occasioned by the soil on which the bank rests. In many cases one can see embanked rivers running in land where valleys formerly existed, under the surface of which exist deep layers of mud partially compressible, and like liquids capable of easily transmitting the pressure in all directions. In such cases the mud yields under the

weight of the banks, and sometimes it is due to this fact, that a rising takes place at some distance in the bed of the river and the adjacent land. The only remedy for this evil is to give very wide bases to the banks, sloping them gently and providing them with banquettes and under-banquettes, and cutting the rising produced in the river bed if it is found to be harmful. In a word, all this work should be carried out till equilibrium is restored.

In the Reno river, in the Province of Ferrara especially, there are remarkable instances of this kind of work.

Passages of water across banks occur sometimes. They are caused by foreign materials, especially vegetation, existing in the body of the bank brought there by animals or by other causes. The passages are almost always fatal to the bank, because the water in flowing across the bare earth, under a certain pressure, erodes the earth, disintegrates the particles and carries them with it, increases quickly in quantity and action, and consequently the hole is enlarged and in a short time the bank is breached.

An effective measure, good and economical, would be to shut the hole on the front side with sacks full of earth, trusses of hemp and oakum.

Another remedy may be found by digging a longitudinal trench in the bank till the passage of water is met with and then closing the passage with rammed earth and "valpastri" and refilling the trench; but this contrivance is very hazardous. The sure remedy is that of creating a safety bank which, when united to the main bank of the river, constitutes a small basin destined to hold up the water passing across the hole. This safety bank may be raised, if necessary, in order to form a basin of stagnant water; by the help of this counter pressure the passage of water is prevented.

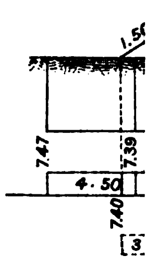
It is understood that after the cessation of the flood the main bank should be knocked down and then reconstructed.

Passage of water by syphoning occurs often and is manifested by jets of water in the adjacent land at a longer or shorter distance from the bank. The water of the river penetrates the meatus of the soil, passes under the banks and then flows up.

In some places such filtrations are numerous and extend over large areas; they are continuous or nearly so and give clear water, and they especially spring up in soils which are mostly sandy. Such filtrations are little or not at all to be feared, and for the protection of the embankment against them it is sufficient to construct a wide and low banquette at the foot of the bank for settling the soil.

PL. VI.

SECTIONS


1.50
7.47
7.39
4.50
7.40
3

In other places muddy filtrations appear suddenly in flood time. They are very dangerous, and must be surrounded by a safety bank for creating a basin of water to make a conterpoise to them and to tend to stop them. If the filtration is very localized and reduced to a single jet, it can be stopped by a bottomless cask well driven in the soil. This cask fulfils the same duty as the safety bank above spoken of.

When frequent filtrations occur along a bank in places where clay is to be encountered at a reasonable depth below country level, the reclamation of the land and the protection of the bank can be obtained by digging along the foot of the bank, going as far down as the clay, and then refilling it with rammed good earth. On the refilled trench a high narrow banquette or a low wide one should be made.

4.—Special Trainings.

It has already been stated that the insufficiency of embankments is sometimes remedied by the reclamation of the land alongside or by the redressing of the rivers. Below I give a few considerations on this subject.

In general the banks are raised along rivers where there is productive lands to be protected; but sometimes the avidity of the people for drawing products from the soil induces them to imprison the rivers between banks before the land has been sufficiently raised by silt deposit. In other cases, banks are also made along rivers to protect lands sufficiently high, but containing here and there certain patches not sufficiently raised by silt doposit, and finally cases can be met with where, for different reasons, a river increases so much in slope with a continuous rising of its bed and water surface that certain adjacent land which was previously not subject to inundation becomes so afterwards.

In each of these cases it is easy to have banks high and thin, but earth for their enlargement or their strengthening would not be obtainable within a reasonable distance. In such cases it is advisable to reclaim by way of colmatage, a large or small strip of land along the banks; and the reclamation may be done by the free expansion of the muddy river or by a limited expansion regulated by culverts, the land to be reclaimed always being surrounded with banks which should be raised with the progress of the colmatage process.

In a winding river, the maintenance of which by embarkment is very coustly, on account of the dangerous state of its concave parts, its course being long and its bed rising notably, some redressing of its

course may often be desirable, to lower the water surface or to render the maintenance of the banks easier and less costly.

In the art of training rivers, redressings are, in general, costly works, but they are of very good and radical effect.

As a result of river embankments it usually follows that immediately or after a certain time the drainage of the adjacent lands is partially or totally prevented, and consequently these lands tend to become marshy. Such a great evil can be remedied by colmatage, by carrying the main drain to tail in the lower parts of the river or in the sea, or by raising the drainage water by artificial means.

These works of reclamation have, as is well seen, a very close connection with those for the protection from river waters.

5.—Methods employed for Closing Breaches in River Banks.

(a) *Principal methods for closing breaches.*—In spite of all the care taken in making banks, breaches may happen therein. Below I give an abstract of the methods used in the Po Valley for meeting such evils.

The closure of a breach is the operation consisting of re-establishing that length of a bank of a river or torrent which has been destroyed by a flood. The difficulties that such an operation presents are produced by the current that takes its way through the breach, and by the disturbance that this current causes on the bottom on which the bank must be reconstructed. Two distinct classes of breaches are ordinarily recgonised. To the first class belong those breaches that occur in the embenkment of a river in which the low water level is below the country surface; to the second class the breaches of those rivers in which the low water level is always higher than country surface, over which it is some times notably elevated, or the river bed is even higher than the country surface.

For closing any breach the first thing to be done is to defend with the greatest care the two heads of the breached bank in order to prevent the breach from becoming wider, and for this materials such as sacks filled with earth, buzzone rubble stone are used. "Palafitte" and in some cases "Penelli," which send the lead of the current far away from the breach, are used.

In order that the work may be efficient it is necessary to be careful not to undertake it before having an abundant supply of materials, otherwise any work attempted may prove to be a failure.

The closing of the breaches of the first class is easy, as the low water surface is below country level.

Ifthe circumstances allow the breach remaining till the river comes to the state of "meagr" then the work will be limited only to the construction of an earthen bank and the protection of it with suitable works of wood or stone, or of both mixed together, taking, however, the utmost care in its execution. Before undertaking the work, it is necessary to consider if it be convenient after the disturbance caused to the soil to construct the bank in the old site or in a new one. Big dimensions should be given to the new bank because its hasty construction from the earth of the banks may not succeed perfectly, or the bank may be exposed to a new flood in a short time. Much care should be taken in joining the new with the old bank and in protecting the front.

If, on the contrary, the circumstances do not allow waiting for the river to fall below country level, the process of closing is the same as for breaches of the second class, only the difficulties are not so great since the principal mass of the water will not pass through the breach but through the river channel below the breach.

We come now to the breaches of the second class. These breaches, when occurring in a river of a great importance, are real disasters, and he who shall direct the operation of closure must expect to sustain a hard struggle. He should have great experience, and great knowledge of the place and of the persons to be employed (engineers, assistants, overseers, etc.). He must be firm in giving absolute orders and keeping discipline, and must have confidence and resolution; he must pass unnoticed the lamentations of the damaged landowners and must not listen to the insinuations of the journals nor to the voices of the critics who are always numerous in such circumstances.

He should study the local circumstances well, fix in general and in detail the project of the work to be done, selecting the establishment and dividing the various duties according to the abilities of the employés.

Besides studying the effective operation of the closure, the engineer in charge should occupy himself also in all other operations which will be necessary or convenient for limiting the extent of the inundation, for providing materials, *i.e.*, of wood in form of needles, beams, joists, poles, fascines; of iron tools; of stone of all possible quarries; of canvas sacks, ropes, rice straw, etc. He should fix all the accessible places from which earth is to be got and then see whether he is going to transport this earth in the common way, or by railway or boats. He should provide himself with lights if neceseary, it may be with common or

with electric light, for any possible night work. The suppliers should be reliable, and the best overseers with their gangs should be employed, profiting by soldiers and especially the pontonniers.

The method used in preference to all others is the following:—

First of all it is necessary to protect the extremities of the damaged bank, *i.e.*, the corners of the breach, with considerable works of wood, stone, or sacks full of earth, or of all these together. The state of the soil in the site of the breach and its neighbourhood should be tested with a vast network of soundings in order to be able to select a line for the closing bank. Such line should be selected on the shallower points, disregarding whether it is long or not.

The construction of the closing earthen bank should be undertaken at both ends of the breach at the same time; it should, however, be always preceded by protection works consisting in most cases of "buzzonati" and "palafitte," or simply with sacks filled with earth, debris or rubble, etc.

With the closing operation of the breach many other operations are associated. First of all the protection of many localities situated upstream of the breach, which, by the strong call of the breach rendering the rush of the current violent, would be threatened with ruin. In case the channel of the river immediately below the breach remains within soil, much good may result from the formation of "repellente" above the breach, making an acute angle with the direction of the current, and so prolonged as to diminish the impetuosity of the escaping water and forcing it towards the lower reach of the river. It is advisable at the same time to press, in the greatest possible measure, the derivations of water in the upper reach, and to diminish as much as possible the admission of water in the river from its affluents, if that can be managed.

In continuing the construction of the closing bank the width of the breach is reduced, and the water finding a smaller waterway, rises, increases in velocity, and scours the bottom and causes the formation of whirlpools. These inevitable evils may be lessened in proportion to the care taken in conducting the work. With the progress of work on the bank, protection works should be pushed, and as soon as the width is reduced to about 20 or 30 metres a sort of canal with two banks should be formed in the breach, in the direction of the current which passes by the breach, but care should be taken to protect the canal thus formed. At the end of this canal several rows of wooden needles, (from 3 to 6) should be driven across, tied and strengthened with beams of wood and iron bolts. Over the stockade thus formed a wooden bridge should be constructed, and at the two ends of this

bridge two large spaces should be formed for receiving the materials to be collected for giving the knot to the breach, *i. e.*, to complete the closure. These materials consist of "buzzoni," sacks filled with earth, and "volpastri." They should be provided in large quantities, and the stockade must be strongly strutted.

To complete the closure of the breach a company of intelligent and energetic men well instructed in the work to be done during the few days preceding this last operation is required. Each man or each squad of men should be given the particular work which the circumstances may call for.

The throwing of the materials in the stockade should be done in the shortest possible time by able labourers, militarily directed. The bigger and heavier materials, the "buzzoni," are placed downstream of the other materials, *i.e.*, of the sacks filled with earth and the "volpastri," and as soon as the materials thrown are raised so as to touch the water surface, or nearly so, the current may be said to have been intercepted, and then the construction of the bank upstream of the stockade of the breach, where the water will be stagnant, can be proceeded with. After the completion of the bank, its protection, heightening, and enlargement can be undertaken, as well as the correction of such defects as may be manifested by and by.

Another variety of the systems used for the complete closure of a breach, consist of using a large canvas of strong sail, which has dimensions suitable to the length of the breach and to the height that water may take above the bottom. It should be large enough to cover as much of the slopes of the canal of the breach and its bottom as possible. For putting the canvas in place, its upper border should be held by men standing on the bridge over the stockade and its lower border attached to ropes held by men placed at some distance above the stockade on another bridge or on boats. The lower border of the canvas should be laden with heavy materials, such as rubble stone placed in bags or in a pocket, made in the canvas, having the shape of a long continuous sack.

After having the canvas thus suspended above the water surface upstream of the stockade, all the men holding the lower border should loosen a little the tension of the ropes that hold, and then the canvas will be immersed in the water, which in a moment carries it to the stockade and makes it adhere and at the same time close the passage of water.

In employing this system it is necessary to be ready with another canvas in reserve, with the materials to be thrown in, "volpastri," sacks

filled with earth, "buzzoni" and earth, because any little accident caused by a labourer who does not make his manœuvre in the proper time, or by a body submerged in the water which prevents the exact adherence of the canvas in all its parts to the slopes and to the bottom, may cause the re-opening of the breach.

There is also another method used for the closure of a breach known under the name of "Il dare la stretta" to the breach. It consists in proceeding to close the breach by constructing the bank from the two ends and covering the bottom by heavy materials, in large quantities, kept in place by strong "palaffite" so as to prevent the scouring. This revetment of the bed will be afterwards raised until a dam emerging above water is got right across the breach. Above such obstacle, "buzzoni," rubble, sacks filled with debris, &c., should be thrown, and as the mass thus formed is somewhat permeable the cavities left in its body can be filled up with sacks filled with earth, "volpastri," soft earth, or a canvas can be used for this purpose. All other details will be proceeded with as in the other methods.

6.—Breach of the Po that occurred in May, 1872, at Garda Ferrarese, Ferrara Province.

The breach in the right bank of the Po, at Garda Ferrarese, happened suddenly at 2 p.m. on the 28th May, 1872, and during the decreasing stage of the flood. The gauge reading at Ponte Lagoscuro at the time was 2·35 metres above zero or guard mark, while the flood that was the cause of the evil had reached its maximum on the previous day, the 27th, with a gauge reading of 2·55 above zero. There happened in reality four breaches, and not one only; two took place in two portions of the bank joined together and situated on the water edge and behind which there existed a borrow pit made for getting the necessary earth to make a new safety bank a little behind, and the other two happened in the safety bank itself.

The upstream breach in the front bank was 280 metres long, the downstream one was 195 metres, and in the safety bank the upper breach was 280 metres and the lower one 300 metres. The disaster was enormous, as the water of the great river escaped into the territories of Copparo, Mesola, Codigoro, Ferrara, Migliarino, and Comacchio, submerging the first three entirely and the fourth partly; the total area inundated amounted to 700 square kilometres. The disaster would have been still greater to the Province of Ferrara had the water not been kept in check by the bank of the Volano, as otherwise the water

would have invaded all the country comprised between the Panaro, the Reno and the Volano, and the flats of Comacchio, destroying at the same time the crops of the year.

To give some idea of the extent of the disaster it may be noted that more than half the discharge of the Po in the reach above Garda was flowing by the above-mentioned breaches on the Ferrarese Campagne.

It was ascertained that the lower breach in the safety bank occurred first, and that the water of the river strongly called by this breach widened the upper cut of the front bank, and that by erosion the upper breach of the safety bank occurred afterwards, while the lower breach of the front bank reached at last the width quoted above.

As soon as the gauge at Polesella read 1·50 metres below guard mark (*i.e.*, when the rush of the water had somewhat passed) soundings were made, from which it resulted that deep irregular holes of 8 metres were formed near the second breach of the safety bank, then holes smaller and more regular in the first upstream breach; in the first or upper breach of the front bank the depth of water was 3·50 metres, and in the lower breach 1·80 metre. Another fact deserving notice was that downstream of the second breach of the front bank, the main bank, for a length of about 300 metres and especially near its junction with the safety bank, was ruined by enormous slippings produced in the internal slope, with deep holes at its footing which rendered a third breach in the bank very possible had protective measures not been taken in proper time.

Finally, it is worth noticing that the enormous volume of inundation water was got rid of into the Adriatic, partly by means of the cut known under the name of Cut of the Sickle made in one of the last sand leashes on sea-shore at the Goro roadstead, but mostly by means of the River Volano.

Immediately after the occurrence of the breach, which at first seemed impossible in a safety bank well off the course of the river, arose the question as to what causes such a disaster must be attributed.

The people who had suffered from the inundation naturally accused the work of the bank, affirming that it was not well executed. Such an accusation was unfounded as the work was done with every possible care. The breach was not produced by water jumping, as it had occurred during the decreasing stage of the flood. It was not produced by erosion because the water in the basin between the front and the safety banks was stagnant. The cause was therefore the syphoning of the water under the safety bank. This fact was evident from the appearance of water in the country at the foot of the bank, and this

was certainly due to the special constitution of the subsoil of the extreme zone of the Po Valley near the Adriatic. In the remote geological periods, the diluvial rains carried away in large quantities vegetal matter from the adjacent mountains and hills, which were entirely covered with forests, and deposited it on what was then the extreme shore of the sea. These vegetal materials were covered by the silt of the river, and in the course of time the fermentation of so much woody material favored the development of the first marshy vegetation, which was renewed century after century and constituted turf which was afterwards covered with sand and earth. That the foregoing is true is proved in the present case of Guarda, for in the bottom of the holes formed by the breaches trunks of trees nearly petrified, and of species which do not grow now in the Appenines were found. Admitting this, it is easy to imagine that where the turf was buried at a somewhat small depth, it was easy for the liquid column, by reason of the great pressure produced during the highest period of the flood, to penetrate by erosion or abrosion through the strata of the turf, and finally burst out on the surrounding country.

As soon as the cause of the disaster was determined, the collection of materials and the organization of the operation of closing the breach was proceeded with. At the same time labourers from all sides flocked to the spot and in a short time 4,000 men were gathered. Four companies of pontonniers with their equipments for bridges and a steamer came from Casal Manferrato, and two gunboats from Venice, and a hundred women were brought for sewing the canvas to be used at the moment of the complete closure of the breach.

With much apparatus, and after constructing military bridges for putting in comunication the different parts of the breached banks, the work took an incredible development on the whole line, which was about 2 kilometres in length.

The struggle was long and hard, the perils many, the evils few and not serious, and the victory splendid.

It was afterwards necessary to decide whether the two breaches in the front bank or those in the safety bank should be closed. For the reasons given below it was decided to close the two former.

1. Because the safety bank, for some defects in the soil on which it stood, could not be considered to be everywhere safe; this was recognised from the existence of turf in the subsoil.

2. Because the line to be followed by the closing dam would present too great depths and the work would be exposed to the great rush of the water.

3. Finally, because the country from which the earth could have been got was inundated or largely covered with sand. It was thought that the earth could not be taken from the front bank as it would not be sufficient for the purpose. On the contrary, the closure of the breaches on the front bank would be somewhat easier, as all the earth of which the safety bank was constructed could be dispensed with; this earth was of large volume and of good quality.

Once this was decided on the works of closure were fixed as follows:—

For the upstream breach.

1. The construction of a frontal "palafitta" of a double row of big poles, nearly in contact with each other; these were disposed along the internal foot of the bank, and filled with materials serving to protect the advancement of the earthwork meant to reduce the opening of the breach without preventing the passage of water.

2. The execution of earthwork for forcing the water into a sort of canal; at the end of this canal the usual stockade was made at the flanks of which two large places were formed for storing the materials necessary for the complete closure, and also for storing the earth to be employed immediately after for re-establishing the bank.

For the downstream breach.

1. The construction of a cross-bank dividing obliquely the basin between the front and safety banks for joining the main bank below the breach to the last part of the safety bank, in substitution to the breached part and the following part below the front bank, which latter being ruined and eroded, as above said, could not be of any more use.

2. The protection of the corners of the breach with "palafitte" similar to those of the upstream breach, filled up and flanked by heavy materials for reducing the breach, to less than 100 metres, if possible.

The rest of the operation consisted in strengthening the front bank between the two breaches with "buzzoni," and stone revetment on the internal side, and with a banquette 8 metres long on the external side. The last portion of the safety bank was enlarged to 8 metres, with banquette of the same width, giving to all a slope of $\frac{2}{1}$.

It is to be noted finally that canvas was used for the complete closure of the breaches, and that these were completely closed on the 22nd July, 1872, whereas the work of closure commenced on the 3rd June.

To give an idea of the importance of the works, I give below two statements showing the quantities and cost.

Quantities used for the work:—

1.	Earth transported by boats	30,949·59	cub. met.
	" " wheel-barrows	94,821·92	"
	" " carts...	407,955·76	"
	Earth of the old bank...	2,945·96	"
	Total earthwork	536,673·23	cub. met.
2.	Needles of fir 6 to 11 metres long, mean thickness 0·20 to 0·30 metres for frontal "palafitti" and stockade.	20,056·09	cub. met.
3.	Girders and poles of fir, thickness 0·16 metres to 0·20 metres, employed for the joining of the "palafitti"	4,312·00	cub. met.
4.	Iron pieces for same	4,221·28	kilog.
5.	Service bridges	3,493·20	cub. met.
6.	Platform for same	2,044·55	sq. met.
7.	Ropes employed	270·62	kilog.
8.	"Buzzoni" of willow filled with rubble, submerged	121,283·00	No.
9.	Rubble, partly submerged on the "buzzoni" and between the rows of poles, and partly for revetting the slopes	21,063·13	cub. met.
10.	Sacks filled with earth, employed	37,689·00	No.
11.	"Volpastri" of earth and straw, partly submerged and partly used in revetting the slopes... ...	625,787·00	No.
12.	Planting with grass the slopes of the bank ...	15,726·80	sq. met.
13.	Mantellatura of mats	496·75	"
14.	Branches of poplar submerged	38·00	"
15.	Canvas employed for the construction of the cross-bank and for the closure of the two breaches... ... ... 4,534 sq. met.		
	Canvas prepared as reserve ... 3,750 "		
	Total canvas... ... ... 8,284 "	8,284·00	sq. met.

Cost of the work:—

(a) *Works executed by contract:—*

1.	Earthwork	£.E.	30,160·500
2.	Timber, iron and ropes	"	5,793·230
3.	Buzzoni, sacks, rubble, and volpastri	"	28,770·500
4.	Mantellatura of slopes...	"	232·880
	Total Cost...	£.E.	64,957.110

(b) *Works done by the Administration:—*

5.	Indemnity for permanent or temporary occupation of land	£.E.	2,302·840
6.	Sum given in advance to contractor for collection of materials and different works, comprising canvas...	"	4,095·110
7.	Indemnity for damages paid to people, other than the preceding indemnity...	"	3,467·000
	Grand Total...	£.E.	74,822·060

IVER.

PL. VIII.

SCALES. { Horiz. 1:20.000
Vert. 1:100

7.—Guardianship of the River Banks in Flood Time.

I cannot close this chapter without giving some information about the way the service of the guardianship of the river banks is carried out in the Po Valley. For this purpose I quote here the instructions issued by the Chief Engineer of the Province of Milan to his subordinates about this service, for the section from the Martizza to the Adda.

" On the river Po, the guardians will be called out by stages, according to the state of the flood and the notices given from the upper reaches of the river. The orders to call out the guardians in the different stages and their dismissal, come from the Chief Engineer or from the Section Engineer.

" As soon as the level of water reaches to within one metre of the guard-mark at the regulating gauges of the different reaches, observations must be made every hour without waiting for special orders. In the necessary hours of repose such observations must be made by the assistant of the overseer.

" As soon as the water level reaches the guard-mark, the overseer should inform by telegraph the Chief Engineer's office of Milan, and without special order should insure the service of observations for the guages of Chiavicone, Regona, Repallini, Rocca and Budriessa.

" As long as the water level remains above the guard-mark the overseers should, every twelve hours, telegraph the office notices of the gauge readings, the state of the banks, and the march of the service in their own reaches; in those that have no telegraph the overseers must be careful to send the notices to the nearest overseers who have a telegraph.

" The extraordinary notices shall be telegraphed at any hour to the offices, to the section engineer, and in cases of peril to the Chief Engineer in person.

" All this is done before the engineer of section joins the spot. But when this engineer comes he will then take in hand the direction of the service and send to the central office the telegraphic notices according to circumstances and orders.

"The following statement (see pages 51, 52, 53) gives the maximum establishment and combustible for each stage. Except in urgent cases the overseers cannot increase or reduce the numbers of the persons indicated in the statement without the previous approval of the section engineer. On the combustible they can make such economies that the climatic conditions may allow. The hydrometrical heights, and limits

of the stages, indicated on the statement are only marked as rules, but the orders of calling out or reducing the guardians will always be given by the section engineer.

"The establishment take service by turns of twelve hours each. Turns commence at 6 a.m. and 6 p.m. every day.

"For this reason two squads are necessary, one for the day and one for the night service. We admit the continuous service only for the store-keepers and the chief guardians, especially when they live at their post and can be substituted during the necessary hours of repose.

"The store-keepers, besides occupying themselves with the distribution and storing of the objects of the stores, keep exact note about how the regulation is applied. They assist the overseers in writing and keeping the current accounts, the nominative notes of the labourers, the tickets, the hourly statements, the reports, all being under the responsibility of the overseers.

"The chief guardian of each post is responsible for the patrolling service and for the presence of the guardians in his post when they are not patrolling. He must not start the gang that has to go down before the return of that coming up.

"The chief guardians, besides disposing and superintending the patrolling service, and writing, signing or checking the tickets relating to the patrolling, may be charged with the observations of the gauges.

"In the twelve hours of service each patrolling gang should do the journey of going and coming to the next post twice in six hours, taking with them the patrol ticket and having it signed by the chief of that post. In the hours of repose between one journey and the other the gangs must not absent themselves from their post.

"Each patrolling gang is composed of two men, each provided with a shovel, a sack, a hunting horn, and, in the night, a lantern. One of the two men walks on the top of the bank and the other at its foot, examining attentively the slopes and the adjacent country.

"In the first stage of the flood, the patrolling gang, composed as above, makes two journeys of going and coming every six hours. In the second stage the patrolling gang travels along the bank, starting from their posts every two hours. In the third stage the gangs start every hour from their post. Each patrolling gang should start at the precise hour without waiting the return of the gang starting before them.

"Each overseer sends, daily to the section engineer, a report on the march of the service, the state of the bank and the total daily expenditure for the guardianship in his reach.

"The overseers should always give notice to his establishment of the above regulations."

I give also (Plate VIII) a longitudinal section of the Po from the tail of the Lambro water-course to the tail of the river Adda, showing the lowest water levels, the levels at which the guardians are called out, and the maximum flood levels, and also the positions of the different guages along this reach. The reach to which the above instructions refer is indicated on this section from Martizza tail to the Adda.

Below I give the table showing the pay of the guard establishment:—

Serial Number.	Classification of the Establishment.	Pay	
		per day.	per night.
		£E. M.	£E. M.
1	Store-keepers	0·080	0·088
2	Chief Guardians	0·080	0·088
3	Observer of guages.	0·080	0·088
4	Messengers on foot	0·072	0·080
5	Patrol	0·064	0·072
6	Orderly	0·064	0·072
7	Cart with horse	0·200	0·200
8	Patrol on horse	0·240	0·240
9	Boat (besides the pay of the boatman and his assistant)	0·020	0·020
10	Rent of locality per post	0·020	0·020

STATEMENT GIVING DETAILS ABOUT THE GUARDIANSHIP.

Reach.	Watercourse.	Maximum Flood.	Localities.	Service of Patrols.	Distances between Posts.	Guardianship for the 1st Stage. Hydrometric height.	Store-keepers.	Messengers.	Chiefs of posts guage observers.	Patrols.	Combustible every 24 hours. Rainy spring.	Autumn-Winter	Guardianship for the 2nd Stage. Hydrometric height.	Store-keepers.	Messengers.	Orderlies.	Chiefs of posts guage observers.	Patrols.	Patrols on horse.	Guardianship for the 3rd Stage. Hydrometric height.	Store-keepers.	Messengers.	Orderlies.	Chiefs of posts guage observers.	Patrols.	Patrols on horse.	Combustible every 24 hours. Rainy spring.	Autumn-Winter
14°	Martizza.		Cascina Geroleni	↑	5·0	Chiavicone Hydr. 52–60	—	—	1	—	·25	·40	6·0–6·80	—	—	—	1	—	—	Above 6·80	—	—	—	1	—	—	·25	·40
		7·77	Chiavicone Hydrometer	↑			—	—	1	2	·25	·40		—	—	—	1	6	—		—	—	—	2	12	—	·40	·50
			Santo Stefano Store-house	↓	5·5		*1	†2	—	—	·50	·80		1	*2	1	1	6	1		1	*2	1	1	12	2	·80	1·00
	Guadiolo.		Abbazia Escape	↓			—	—	1	2	·25	·40		—	—	—	1	6	—		—	—	—	1	12	—	·40	·50
			Seriolo Escape	↓	6·0		—	—	1	—	·25	·40		—	—	—	1	—	—		—	—	—	1	—	—	·25	·40
			Rottino Escape R. 15°	↓																								
15°							1	2	4	4	1·50	—		1	2	1	5	18	1		1	2	1	6	36	2	—	2·80
	Po River.		Chiavicone Hydrometer R. 14° ...	↑		Regona Hydr. 5·0–5·80							5·8–06·60							Above 6·60								
		7·53	Regona Hydrometer	↑	5·0		—	—	1	—	·25	·40		—	—	—	1	—	—		—	—	—	1	—	—	·25	·40
			Caselli Landi Store-house	↓			*1	1	—	2	·50	·80		1	1	1	1	12	1		1	1	1	1	24	1	·80	1·00
			Ronchi Escape	↓	4·0		—	—	—	1	·25	·40		—	—	1	—	—	—		—	—	1	—	—	—	·25	·40
			Cascina Santa Maria	↓	4·5		—	—	—	—	—	—		—	—	—	1	6	—		—	—	—	1	12	—	·40	·50
			Rottino Escape	↓			—	—	1	—	·25	·40		—	—	—	1	—	—		—	—	—	1	—	—	·25	·40
							1	1	2	3	1·25	2·00		1	1	2	4	18	1		1	1	2	4	36	1	1·95	2·70

* During the 1st stage the store-keepers take charge also of the service of chief guardians.
† One of the two messengers is charged with the service of bringing the notices from upper reaches and goes between Placenza and Santo Stefano.

STATEMENT GIVING DETAILS ABOUT THE GUARDIANSHIP—*(continued)*.

Reach.	Water-course.	Maximum Flood.	LOCALITIES.	Service of Patrols.	Distances between Posts.	Guardianship for the 1st Stage.					Combustible every 24 hours.		Guardianship for the 2nd Stage.							Guardianship for the 3rd Stage.							Combustible every 24 hours.	
						Hydrometric height.	Store-keepers.	Messengers.	Chiefs of posts guage observers.	Patrols.	Rainy spring.	Autumn-Winter.	Hydrometric height.	Store-keepers.	Messengers.	Orderlies.	Chiefs of posts guage observers.	Patrols.	Patrols on horse.	Hydrometric height.	Store-keepers.	Messengers.	Orderlies.	Chiefs of posts guage observers.	Patrols.	Patrols on horse.	Rainy spring.	Autumn-Winter.
			Cascina Costa...	↓		Rocca Hydrometer 4·20–5·00	—	—	1	2	·25	·40	5·00 – 5·70	—	—	1	1	6	—	Above 5·70	—	—	—	1	12	—	·40	·50
			Repelleni Hydrometer...	↓	3·7		—	—	1	—	—	—		—	—	—	1	—	—		—	—	—	1	—	—	·25	·40
			Rampa Malpeneata...	↑			—	—	1	—	·25	·40		—	—	—	1	—	—		—	—	—	1	—	—	·25	·40
			Rocca Hydrometer	↑	3·7		—	—	1	—	·25	·40		—	—	—	1	—	—		—	—	1	1	—	—	·25	·40
			Castelnuovo Store-house	↓			1	1	—	4	·50	·80		1	1	1	1	12	1		1	1	—	1	24	1	·80	1·00
			Budriessa Hydrometer...	↓	3·3		—	—	1	—	—	—		—	—	—	1	—	—		—	—	—	1	—	—	·25	·40
			Casino Escape...	↑	3·2		—	—	1	—	·25	·40		—	—	—	1	—	—		—	—	—	1	—	—	·25	·40
			Garda Store-house...	↑			1	—	—	2	—	—		1	—	1	—	6	—		1	1	1	—	12	—	·40	·50
							2	1	6	8	1·50	2·40		2	1	2	7	24	1		2	2	2	7	48	1	2·85	4·00
			Budriessa Escape	↑		Lardera Hydromet.	—	—	1	—	·25	·40		—	—	—	1	—	—		—	—	—	1	—	—	·25	·40
			Casino Escape...	↑	3·2		—	—	1	—	·25	·40		—	—	—	1	—	—		—	—	—	1	—	—	·25	·40
			Garda Store-house...	↓			1	1	—	4	·50	·80		1	1	1	1	12	1		1	1	1	1	24	1	·80	1·00
			Lardera Escape	↓	3·4		—	—	1	2	·25	·40		—	—	—	1	6	—		—	—	—	1	12	—	·40	·50
			Last consortium embankment ...	↓	3·1		—	—	1	—	·25	·40		—	—	—	1	—	—		—	—	—	1	—	—	·25	·40
							1	1	4	6	1·50	2·40		1	1	1	5	18	1		1	1	1	5	36	1	1·95	2·70

CHAPTER III.

General Remarks on the Irrigation Works in the Po Valley.

1.—Abstract on the Irrigation in the Po Valley.

From early times studies were made with great perseverence in those regions where profits could be drawn from the water-courses for the benefit of agriculture. These studies consisted of researches made on the natural springs, and the well-supplied perennial water-courses, and on the conditions most favourable for the supply of water for irrigation purposes.

The Po Valley, as we know, is comprised between the Alps and the Apennines and terminates at the Adriatic. The River Po and other long rivers fed by glaciers and large catchment basins are situated in this valley.

The proportion between rain water that flows superficially and escapes into the sea and that utilized for irrigation and production of motive power is great in the Po Valley, as appears from the following table which gives most valuable information about this valley.

The proportion between the mountainous parts and the plain in the Po Valley is from 1 to 3. In the plain the area of the barren land to that of irrigated land is 1 to 1 in Piedmont and Lombardy, and 1 to 2 in Venitia and Emilia.

Regions.	Provinces.	Total area in acres per Province.	Area of plain in acres.	Area of irrigated land in acres.	Population.
Piedmont ...	Cuneo ...	1,797,840	466,956	267,069	664,416
	Turin... ...	2,508,480	547,627	302,179	1,063,862
	Alessandria.	1,184,880	360,000	38,109	746,441
	Novara ...	1,587,360	944,203	455,335	704,233
Total for Piedmont ...		7,078,560	2,318,786	1,062,692	3,178,952

Regions.	Provinces.	Total area in acres per Province.	Area of plain in acres.	Area of irrigated land in acres.	Population.
	Brought forward...	7,078,560	2,318,786	1,062,692	3,178,953
Lombardy ...	Pavia... ...	815,760	583,200	331,536	478,618
	Milan ...	754,320	683,760	594,997	1,125,553
	Como... ...	671,040	165,232	6,451	536,641
	Sondrio ...	749,520	16,660	20,160	124,914
	Bergamo ...	678,720	131,668	133,231	404,040
	Brescia ...	1,146,960	470,400	266,748	475,467
	Cremona ...	426,720	392,952	238,051	304,507
	Mantua ...	566,160	513,120	36,000	300,311
Totals for Lombardy...		5,809,200	2,956,992	1,627,173	3,750,051
Venitia ...	Verona ...	763,440	395,611	62,193	394,868
	Vicenza ...	668,400	210,525	36,480	401,765
	Belluno ...	803,280	83,760	232	195,419
	Udine ...	1,588,560	720,000	37,716	528,559
	Treviso ...	592,080	400,696	7,320	381,082
	Venice ...	455,520	527,529	28,800	356,273
	Padua ...	495.120	438,031	23,395	397,421
	Rovigo ...	399,600	404,685	18,000	218,574
Totals for Venitia ...		5,766,000	3,180,837	214,136	2,873,961
Emilia... ...	Piacenza ...	565,200	232,483	27,362	234,603
	Parma ...	794,400	226,447	21,960	277,293
	Reggio ...	520,800	254,047	20,584	253,486
	Modena ...	617,520	316,574	19,473	289,247
	Ferrara ...	630,480	628,024	3,261	230,144
	Bologna ...	862,320	477,199	61,665	461,172
	Ravenna ...	511,920	321,072	7,668	226,667
	Forli... ...	476,880	169,680	993	254,734
Totals for Emilia ...		4,979,520	2,625,526	162,966	2,227,346
Grand totals for the Po Valley		23,633,280	11,082,148	3,066,967	12,030,310

From this table it is seen that the largest irrigated areas lie in the western part of the valley where the greater afluents of the lakes are situated and where the country slope is sufficiently great to allow easy irrigation, while in the eastern part very little irrigation is carried on along the foot of the mountains. The two regions of Lombardy and Piedmont forming the greater part of the upper or western valley, are the classic countries of irrigation known for centuries. In these two regions the irrigated land forms about eight-tenths of the area, to the

east of the Adda, on the contrary, the irrigated area is hardly five-tenths of the area of the district. On the right side of the Po the irrigation is not so extensively carried on. Although there exist many small rivers coming down from the Appenines, yet they bring very little water, as the rainfall on these mountains is very small.

2.—Short Historical Review.

The most ancient works are probably to be found in Venitia, where in the 9th and 10th centuries, canals already existed, although meant more for navigation and water supply than for irrigation purposes. In the 11th century a canal taking from the rivers Secchia and Tanaro was made at Modena for navigation and irrigation. This canal was the cause of disputes and wars with Reggio.

In Lombardy, irrigation canals deriving their water from the small rivers Olona, Sveso, and Vettabia, near Milan, already existed in 1140, and there probably existed also at that time a canal, the Ticinello, taking from the Ticino, and running from Tornavento to Abbiatagrasso. In 1177 this canal was brought to Milan and in 1257 it was used for navigation; this was before locks were invented. In 1270 it took the name of "Naviglio Grande." The good results obtained from this canal led the city of Lodi to make, in 1220, the Muzza canal, taking from the Adda; this was exclusively utilized for irrigation. In the beginning of the 14th century the Roggia Fusa was thrown off the Oglio in Brescia Province, and shortly after the Naviglio Civio was thrown off the same river in Cremona Province, and some time after the Pozzola canal was thrown off the river Mincio in Mantua Province. In 1359 under Galeas Visconti II, a canal was made from Milan to Pavia, and in 1457 Franceso Sforza I utilized it for navigation; but it was neglected and quickly fell out of use and thus it remained till the present century.

During the reign of the same Sforza, in 1457, the Martesana Canal was made to connect Milan with the Adda and was used for both navigation and irrigation. To connect Milan with the Como Lake a canal was commenced in 1518 at Paderno, along the Adda, for avoiding the cataracts existing in the bed of that river. All sorts of adversities came in its way and it was not until 1775 that it was completed. Leonardo da Vinci had by that time invented the locks and a canal, the "Fossa Interna," provided with five of them was made across the whole city of Milan. Thus in 1775 the city was put in connection with the lakes Maggiore and Como.

In 1819 the Austaian Government had completed the Pavia Canal and made it navigable, and consequently Milan was that year put in navigable communication with the River Po.

In Piedmont, important canals were thrown off the Elvo in 1219, the other greater works took birth in the 15th century.

Duke Emmanuel Philibert of Savoy did much for irrigation; by his help the tax for irrigation water was not gathered from the irrigated land which was far distant. In 1560 this duke, under the protection of Henry II of France, commenced the Caluso Canal and by the end of his reign the canal of Cuneo was projected and that of Ivrea completed. Most of the canals of Piedmont are in private hands, in contrast with Lombardy, where most of the important canals belong to the Government. In 1746, however, the State Domains bought the Caluso Canal; in 1785 the Cigliano Canal, and in 1839 the Charles Albert Canal were put under the State management.

The more recent canals in the Po Valley will be spoken of in the chapters devoted to irrigation in Piedmont and Lombardy.

CHAPTER IV.

Irrigation in Piedmont.

1.—Historical Review.

The first attempts at irrigation works made in Piedmont on a large scale, go back to the 12th century.

From that time dates also the first impulse, the studies and the works continued constantly since then—the studies in the time of war and the works in the periods of peace. All consisted of directing the waters to the zones situated between the Dora Baltea and the Ticino for the benefit of agriculture.

The Ivrea Canal, the derivation of which is the highest on the Dora Baltea, was the starting point of these works. The Naviletto deriving from the Mandria was also made at the same time for irrigating the accessible plain of the Vercellese.

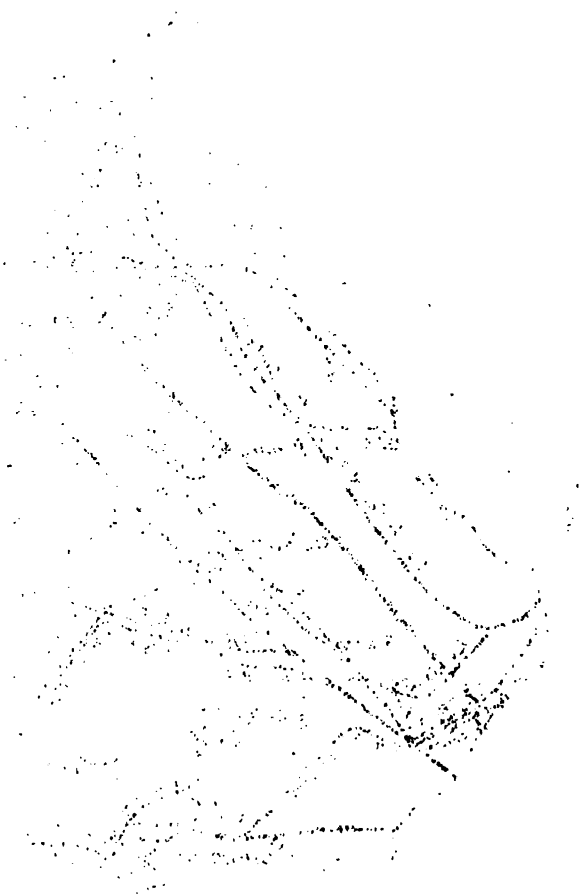
Afterwards, for extending the irrigation from the Dora Baltea to the successive territories extending from Salussola and Buranzo to Cascine di San Giacomo towards the Sesia, a project was studied for directing the water of the Ivrea Canal to the Viverone Lake and re-extracting it and conveying it in a new gallery, which was to be made under the hills situated on the left of the Dora Baltea and which was to open near Cavaglia at the locality known under the name of Dora Morta. This project being too expensive and difficult, was abandoned and a better one was substituted for it. The second project consisted of making a second derivation of the Dora Baltea in the Villareggia territory. It was not until 1785 that this project was carried out, and the canal fed by it was called Cigliano or Depretis Canal.

The first studies made on this project were completed towards the middle of the last century. They were intended for the construction of a large canal of 80 cubic metres discharge per second. This canal was to irrigate the high Vercellese and to tail into the river Sesia, a little below the village of Lenta. It was also to feed the deficient derivations of the Busca and Rizzo-Biraga canals and to increase the irrigation water in the Novarese and Lomellina between the Sesia and the Agogna down to the irrigation system of Sartirana.

PL. IX.

○Valle	------ Limits of circonscription.


Pombia
Gallarate
Marano Ticino
Busto Arsizio
Roggia Molinara di Oleggio
progetto Celli
Oleggio
Bellinzago
F. Ticino
Cavo Cit
Cameri
Cuggiono
Cavour
Galliate
Romentino
Magenta
Roggia Mora
Cerco
NOVARA
C.S. Martino
Trecate
R. di Città
C.S. Casciano
Cavo dei Termini
R. Nuova
Roggia
Cerano
Subdiram di Vigevano
J. Tardoppio
Sozzago
Arbogna
Garbagna
Terdobbiate
Naviglio
Tornaco
Cassolnuovo
Roggia Mora Saporita
Prolungamento
Naviglio Sforzesco
Vespolate
Cavo Bassi
Gravellona
Borgo Lavezzaro
Vigevano
Cilavegna
Nicorvo
REFERENCES.
Existing
Proposed
Irrigable land
Private irrigati
Territory irrigated
on the W. of the Sesia.
Lands irrigated by Cigliano
Lands of Galliate, Romentino, Trecate
Lands irrigated by Montebello Canal.
Limit of rice cultivation towards mountain.
Boundary of Province.
Limits of circonscription.
Castelnovetto
Zeme
Busca
Valle



The head works were opened to receive such supply, but the section of the canal (Cigliano) was reduced to discharge 18 cubic metres only per second for the following reasons.

In the Novarese and Lomellina the prevailing cultures till then were rice and grass. The rice wants abundant water in the spring for its sowing, and the meadows require abundant tepid water in winter for their submersion. The Dora Baltea, which is low in spring and frozen in winter, could not feed the Cigliano Canal sufficiently to enable it to fulfil the duty assigned to it by this vast project.

The project of a derivation from the Po near Crescentino, below the confluent of the Dora Baltea had been already conceived, nearly a century before, to fulfil the same purpose as that provided for by the abandoned project. This derivation, which was meant to be fed by the united waters of the Po and the Dora Baltea, abundant in spring and temperate in winter, would have solved all difficulties.

The derivation which was to take from the Po at Crescentino, was brought further upstream to Chivasso. This is the derivation for the great Cavour Canal which will be spoken of in detail further on.

To the construction of the Cigliano, which was completed in 1785 as stated above, succeeded a period of nearly complete inaction, caused by the Napoleonic wars which ended in 1815.

The only work of importance made in this period was the construction of the Cavo Magrelli which irrigates the lands of Morana, Balzola, Villanova, Terranova and Casale on the left of the Po.

In 1820 the State acquired the Ivrea Canal and commenced the work for the extension of irrigation, which was continued with varying activity till after 1840, when by the bold initiative of the engineer Carlo Noé came an extraordinary vigour.

Several branches of the Ivrea Canal were made by that engineer on the Vercellese Plain from Tronzone to Asigliano. He acquired for the Government the right over the water of the common of Tricerro and constructed the Rive Canal, fed from the canals of Cigliano and Rotto. The Rive Canal benefitted the lands in the low Vercellese which until then were nearly uncultivated.

The truce, caused by the political affairs, during the wars of 1848 and 1849, was utilized for the study of a series of improvements to which the Vercellese owes the transformation of its ancient agriculture into a true and proper industry.

Besides the Domanial Canals there are private ones taking from the Dora Riparia, the Stura, the Orco, the Sesia and the Ticino. Some of them are somewhat important, such as the Caluso Canal taking from

the Orco with a discharge of 10 cubic metres and the Langusco Canal taking from the Ticino with a discharge of 18 cubic metres; but in general the private canals in this country are of little importance and offer small interest from a technical point of view.

2.—Domanial Canals.

A. *Branches of the Dora Baltea.*

(a) *Ivrea Canal.*—This canal was opened in 1468 and passed to the Government in 1820, as already stated. It derives from the Dora Baltea on its left bank to the south of the city of Ivrea by means of a permanent weir across the river. Just below the head, the water is used for turning mills; by means of an escape this water reunites with the Dora. The discharge of the canal is 24 cubic metres per second. This discharge is regulated by means of an escape on to the Dora Baltea. Down to Cigliano the canal runs on the slope of the channel of the Dora Baltea. Below Cigliano it enters into the plain and strikes northward till it reaches Santhia and passes afterwards under the Canal Depretis and then turns southward to Vercelli. The total length is not less than 74 kilometres; the irrigated area is 28,809 acres, thus giving a duty of 0·69 litres per acre per second or 59 cubic metres per diem, which is an extremely low duty. This must be attributed to the cultivation of rice, which is carried on here on a large scale.

The Ivrea Canal has a large branch on the left which passes at the foot of the high land, three branches on the right and two smaller branches on the left, besides the numerous heads for irrigation deriving directly from the main canal. The remaining water after Vercelli escapes into the Sesia, whence it is retaken at the left bank by the derivation of the Sartirana irrigation system, which re-uses it on the lands extending from the Lower Lomellina to the Agogna and the Po.

(b) *Cigliano or Depretis Canal.*—This canal also takes off the Dora Baltea a little further downstream than the offtake of the Ivrea Canal. As already stated, it was constructed in 1785 during the reign of Vittorio Amedeo III, and was a partial execution of a large project the object of which was the construction of a derivation of 80 cubic metres discharge per second. This was meant for the irrigation of the high Vercellese, and to supplement the Sesia River in the Lenta territory with water for the derivations of the canals Busca and Rizzo-Biraga in Novara Province.

This project was abandoned, for reasons already given, and the canal, which was constructed with a reduced section of a discharge of only 18 cubic metres, flows suddenly from the high lands, and with two cataracts at the Brimenga and near Carisio tails in the Elvo torrent.

By a decree issued on the 17th July, 1858, No. 2912, the original section of the canal was enlarged and its supply was increased to a maximum of 55 cubic metres per second. The total expenditure for this enlargement amounted to £.E.69,231.

With such a supply it was possible to feed the Ivrea Canal near Santhia; to escape a large quantity of water into the Elvo torrent in the territory of Carisio to make up the supply required for the existing domanial derivations and that of the canals of Vercelli on the Cervo torrent; and to pick up the balance in the Sesia at the dam of the Sartirana irrigation system for the proper supply of this system.

Moreover, a well studied project for feeding the Cavour Canal from the Cigliano, through the Ivrea Canal, was completed in March, 1899. It consisted of the enlargement of the Ivrea Canal from its meeting at Santhia with the Cigliano Canal to its meeting with the Cavour Canal, under which it passes now by a syphon and goes towards Vercelli to irrigate some land in its neighbourhood. At the point of intersection of the Ivrea and the Cavour Canal a junction was made to give 30 cubic metres per second to the Cavour Canal. This junction will be treated further on in detail in connection with the Cavour Canal.

(c) *Canal del Rotto.*—Below, and at a little distance from the derivation of the Depretis Canal, the derivation of the Canal del Rotto is situated on the left bank of the Dora Baltea in the same territory of Villaregia.

Its construction dates back to the 14th century, and for that reason it represents the first attempt of irrigation on a large scale, before the construction of the Ivrea Canal in Piedmont.

The situation of the dam on the river is bad. It has been ruined three times by the flood of the river and has been reconstructed.

If in future this should happen again, it will be as well to consider if it would not be more convenient to feed this canal from the escaped water of the canal Depretis, which would serve for the production of the motive power of the hydraulic elevator of Cigliano, and to see if the canal Depretis with its dam can suffice for the two canals. The Cigliano elevator will be spoken of further on in detail.

There is no doubt that this combination would be all right and great expense would be spared by the suppression of the dam in the river for the Canal del Rotto, since the water that escapes the derivation of the

Depretis Canal can be picked up below, at the derivation of the Farini Feeder to the Cavour Canal which will be spoken of later on.

But it would be necessary before taking any decision to ascertain what influence on the regimen of the river the suppression of the Rotto dam would exercise. The Rotto dam serves now as safeguard to the Depretis dam lying upstream of it.

In its first reach the Rotto Canal turns an important flour mill, and afterwards throws off, on the right, the Camera Canal which develops itself in the Vercellese plain near the Po. Below the Camera Canal the canal Del Rotto is divided into three branches, the Re the Bianzé and the Livorno Canals.

(d) *Cigliano Hydraulic Elevator for Irrigation.*—This elevator is situated in the territory of Vellaregia at the base of the ramp of the Dora Baltea on which the canals of Ivrea, Cigliano, and del Rotto are also situated. The first is situated above the middle of the coast, the second in the middle of the coast and the Rotto Canal at its base.

All these canals irrigate the lands situated on their right side, leaving, on the left of the Ivrea Canal, which is the highest, a plain deprived of water having an area of about 19,047 acres in the territories of Moncrivello, Villaregia, Cigliano, Borgodale, Alice Castello and Cavaglia.

For providing free flood irrigation to this land many studies were made which had no issue, as the enormous expense which would have been incurred was much more than to counterbalance any profit to be obtained. Consequently, lift irrigation was thought to be the most economical scheme to be resorted to, and Cavaliere Stefano Romagnano studied this question and drew up a project for an elevator which Cavaliere don Evasion Ferraris executed. In this project the Dora Baltea was to supply water both for producing motive power and for irrigation. The installation provided water only for 3,571 acres and it is to be regretted that the attempt was not made on a larger scale, the available dynamical power and water for irrigation are sufficient for the whole unirrigated area of 19,047 acres.

The elevator has worked regularly since 1880 and provides water for the irrigation of 3,571 acres of land in the territories of Moncrivello, Villaregia, Cigliano, and Borgo d'alé

The canal Depretis turns the motors with 8 cubic metres of water which are escaped afterwards into the canal del Rotto.

The pumps worked by the motors receive the water from the Ivrea Canal and force it to the height of 40 metres, on to an irrigable plain, in a continuous quantity of 1,300 litres per second, which is ample for 3,571 acres.

This quantity of water is gathered up in a canal and conducted and distributed on the lands.

CIGLIANO PUMPING STATION.

All of this is the work of a "consortium" formed among the proprietors of the lands irrigated in the above-named four localities.

The highest canal, the Ivrea, is 20 metres higher than the Depretis Canal and 119 metres distant, measured on the horizontal, while between the Depretis and the Canal del Rotto there is a difference of level of 6·50 metres only. In its present state the Ivrea Canal can supply the irrigation water required for the tract under consideration, but it is unable to give the water required for producing the motive power for lifting it. The motive power is supplied by the Depretis Canal which, after having done its duty, escapes into the Canal del Rotto.

Twenty-three complete projects were submitted for carrying out the scheme ; the one submitted by the firm Roy and Co., of Vevey in Switzerland, was accepted. This firm undertook to insure a supply of 1,230 litres of water per second, and the price of the machines was fixed at £E.8,846. Adding to this sum the cost of the building, the total cost of the work becomes £E.11,538. It was stipulated that the firm should take the working of the machines for an annual indemnity of £E.307.700 during ten years, after which they should hand over the

whole business to the "consortium." It was further stipulated that the machines should consume 9 cubic metres of water per second for lifting the greatest possible quantity of water for irrigation. In 1880 the machines were put in work, as already said, but the results were unsatisfactory. The pumps thumped so heavily that the buildings could not resist and the machines could scarcely work at a small part of their full power, and so the irrigation was extremely defective. Later on, improvements were introduced by the firm of Odero, after

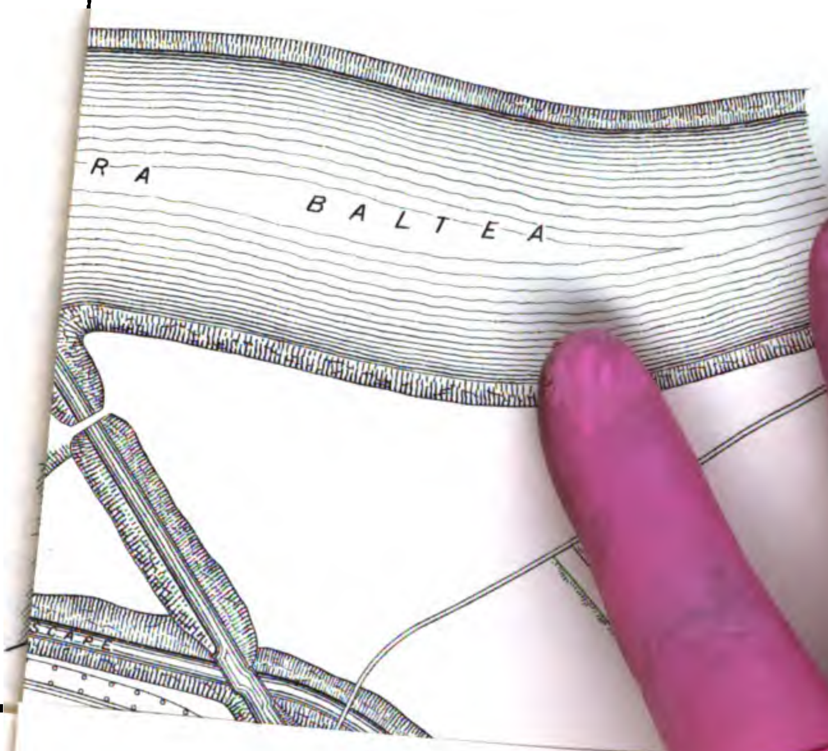
CIGLIANO PUMPING STATION.

which the defects of the system were removed, so that the machines now work regularly and the irrigation goes on fairly well.

The Government on their part conferred upon the "consortium" the water for the production of the motive power gratis, and the water for irrigation at the rate of £E.19.230 per Modulo Italiano. They have done well. With such concession they contributed to enrich a poor land which became now such, that without excessive uneasiness it is able to support the amortizement of the expended capital as well as the expenses annually incurred for working the lifting machines.

On Plate X are shown the details of the installation with the turbines erected on the Canal Depretis from which the water for producing the motive power is supplied. This water, after having done its duty, escapes into the Canal del Rotto through a channel 350 metres long, tailing into this canal at only a short distance below its head. There are four turbines of the Girard system, each turbine is calculated

PL. X.



to be set in work by 2,400 litres. On both ends of the horizontal axle of each turbine are placed two wheels which by means of cranks transmit the motion directly to the pistons of the pumps placed above the turbine. The pumps are provided with air reservoirs.

The irrigation water is supplied by the Ivrea Canal by means of a 1·20-metre diameter iron pipe which divides into four suction pipes within the building. The delivery pipe, which also has a 1·20-metre diameter, is placed on masonry pillars and conveys the water to a masonry basin situated at a height of 40 metres above the pumps. From this basin the irrigation water is delivered to the "consortium."

The machines actually use 8 cubic metres of water for the production of power, this quantity having 6·50 metres fall would lift 1,300 litres 20 metres high, and thus the pure effect would be—

$$1300 \times 20 : 8000 \times 6{\cdot}50 = 50\%.$$

Under these circumstances the lifted water can be increased to 1,500 litres.

B. *Canals taking off the Elvo and Cervo Torrents.*—In the years 1857-59 the canals derived from the Elvo and Cervo torrents were acquired by the State. The reason for the acquisition of these canals was to acquire the right of conducting through them, into the Sesia, the water of the Depretis Canal issued from the Dora Baltea as already stated in order to feed the irrigation system of Sartirana near Palestro.

C. *Canals taking off the River Sesia.*—Starting from upstream and going downstream, the canals that take off the Sesia River are as follows:—

1. On the left: Mora Canal (Prato).
2. On the right: Gattinara Marchionale Canal (Gattinara).
3. On the right: Gattinara Comunale Canal (Gattinara).
4. On the right: Lenta Canal (Lenta).
5. On the left: Busca Canal (Gemme Carpignano).
6. On the left: Rizzo-Biraga Canal (Carpignano).
7. On the left: Sartirana Canal (Palestro).

The first four canals are private and the last three domanial.

The Busca Canal has existed since 1380. It derives from the Sesia by means of a dam built at Lenta across this river, passes under the Cavour Canal, and crosses the Rizzo Biraga Canal. It has a length of 55 kilometres with branches of 27 kilometres.

Parallel to this canal and at a short distance from it runs the Cavetto Busca which originates in the Mora Canal between Fora and Briona,

and down to Bordignana it has a length of 53 kilometres. It also takes water from the Busca Canal through the Molinara di Carpignano.

The Cavo Bagnolo, which derives its water from the Sartirana system near Santa Maria di Bognolo forms also part of the network of the Busca Canal. It conducts the water down to Bordignana so that in case of deficiency it may assist the Busca and Cavetto Busca Canals in the irrigation of the land under their command.

The Busca Canal with the Cavetto Busca and the Cavo di Bagnolo were acquired by the Domains by virtue of a law dated the 19th March, 1885.

The Rizzo-Biraga Canal has existed since 1488 and takes its water from the left bank of the Sesia. It was acquired by the Domains in March, 1855. Its development is 10 kilometres, and consequently it is less important than the Busca Canal.

The Sartirana Canal, the lowest branch of the Sesia, derives its water from this river at Lenta and goes down till it tails into the Po. It is equally old and became Domain property in 1857. It is commanded by a large dam across the river, 315 metres long, and has a head sluice to regulate the admission of the water into it. Its length is 29½ kilometres and its discharge 25 cubic metres. With the system of this canal is connected that of the Gamara Canal which is fed by spring water that it picks up in its long winding and depressed course which runs through land of marshy constitution.

All the above canals belong now to the system which is regularly fed by the Cavour Canal. The private small system fed by the rivers, or by the springs which are situated within the irrigation system of the Cavour Canal, are almost all benefitted, more or less, by the indirect feeding of this canal.

Remark.—In the above review of the canals of Piedmont I have not entered into details about their construction, as so doing would be too long and void of interest. I reserve till further on details of the construction of the Cavour Canal which are most interesting.

3.—History of the Cavour Canal.

Before the construction of this canal the part of Piedmont lying between the left bank of the Po and the foot of the Alps was irrigated chiefly by canals derived from the Orco, the Dora Baltea, the Sesia, the Agogna, the Terdoppio and the Ticino. Of these rivers the Ticino

supplied, on its right bank, a few small canals only, whose irrigation was confined to the country bordering on the river. The Dora Baltea was well utilized in the Vercelli territory. The Orco supplied the Caluso Canal; and the country between the Sesia and the Ticino, comprising the Novarese and Lomellina was dependent principally on the former river, Agogna, and the Terdoppio, all of which partake too much of the character of torrents, having little water during the summer months. The irrigation of these two tracts was then always very precarious.

The idea of employing the Po otherwise than a drainage line for the country seems to have occurred to the Dominican Father, Tommaso Bertone, who, in a speech published at Turin in 1633, suggested the project of a canal to take from the Po at Crescentino.

In 1840 a landlord from Vercelli, Francesco Rossi, proved the possibility of such a canal and the engineers Carlo Noè, and Fagnani confirmed the idea in 1846. In 1852 Noè drew up a project which he presented to the Minister Cavour for a canal to take from the Po at Chivasso, above the tail of the Dora Baltea, but below the Orco, Malone, and Stura. If the offtake of the canal had been put more upstream it would have missed the supply of these torrents, and the line of the canal would have met the Dora Baltea under less favourable conditions.

The canal starting from Chivasso was to be carried over the Dora Baltea and the richly irrigated country lying between that river and the Sesia, increasing the supply of the existing canals in the Vercellese but reserving most of its water for the irrigation of the country beyond, putting those parts already watered beyond the risk of failure at critical periods, and extending the benefits of irrigation to places hitherto dry.

In 1853 a contract with the "Société des Eaux de Paris," for the execution of the work "à forfait" for £E.1,384,615 was made with the guarantee of the State. But this contract was afterwards cancelled and Count Cavour preferred to have the work carried out by the State.

The political complications of 1854-55 and the wars of 1859-61 and the death of Count Cavour, which took place in 1861, delayed the undertaking of the work. But before the death of Cavour the insistance and claims of the people induced the Government to take a decision for compensating in a way the losses sustained from the enemies' invasion, the civil wars, and the requisition for war to which the population were subjected in the spring of 1859. A new contract was made with English and French capitalists on the 9th May, 1862,

and approved by a law promulgated on the 25th August of same year (sub No. 776).

The capital for the construction of the work *à forfait*, comprising the interests and the expenditure for three years, was fixed at the sum of...	£E.2,053,846
Another capital of	„ 780,769
was imposed on the concessionaries which corresponded to the cession of the old Domain Canals; and finally a sum of	„ 242,307
was reserved at the disposal of the Government for the construction and for the acquisition of secondary canals. Summing up, the total amount of the concession was	£E.3,076,922

The Government guaranteed on this capital, as the work was completed and taken over, an interest of 6% and the amortizement in fifty years.

The statute of the society was approved of by a Royal Decree dated the 14th September, 1862.

This statute admitted in favour of the society a premium as "apport" of	£E. 57,693
The lump sum for the work was fixed at	„ 1,837,975
and the expenditure of the administration, exclusive of that of the engineers	„ 28,846
to which was added the value due to the Government for the old Domanial Canals of	„ 780,769
and the funds reserved to the secondary canals at...	„ 242,307
Add reserve of the society of	„ 129,332
on the social capital, and the total will be	£E.3,076,922

The work was commenced in the first months of 1863 and completed by the 15th April, 1866, *i.e.*, in less than three years.

After the completion of the work the Society's bankruptcy was proclaimed on the 17th July, 1868, but the bankruptcy was solved by an arrangement made on the 30th November, 1868, by virtue of which all the debts of the society were integrally paid, leaving a free annuity of £E.19,231 to be divided among the bankrupt shareholders. This annuity was afterwards converted into a consolidated rent 5% of £E.33,654, divided at the rate of £E.0·675 among the 50,000 shares which were withdrawn from circulation. Later on the Government by a law of the 16th June, 1874 (No. 2001), purchased the concession of the Cavour Canal.

4.—Available Discharges of the Domanial Canals.

The mean discharge of the Po at Chiavasso, where the offtake of the Cavour Canal is placed, is 70 cubic metres per second; the minimum

discharge in July and August is 40 cubic metres. In 1882, however, this discharge had fallen as low as 28 cubic metres.

The Dora Baltea has a minimum discharge of 30 to 50 cubic metres from October to the middle of May.

The Sesia with its two affluents, the Elvo and Cervo, gives between October and June, only 20 cubic metres.

The whole network of the Domanial canals gets the following quantities of water:—

NAMES OF RIVERS.	From October to June.	From June to October.
	Cub .met.	Cub. met.
Po at Chiavasso	90	60
Po at Casale	10	10
Dora Baltea	40	160
Sesia, Elvo and Cervo	50	20
Fontanili (springs)	10	15
Total	200	265

The maximum capacity of the Domanial network is as follows:—

	Cubic metres.
Canal Cavour. from the Po...	110
Canal Gazelli, from the Po...	2
Canal Lanza or Casale, from the Po...	10
Canal Ivrea, from the Dora Baltea	20
Canal Deprrtis or Cigliano, from the Dora Baltea...	55
Canal del Rotto, from the Dora Baltea	18
Canals taking off the Elvo and Cervo	10
Canal Busca taking off the Sesia	22
Canol Rizzo-Biraga	18
Canal Sartirana	25
Total	290

From the foregoing it is apparent that there is a deficiency of 25 cubic metres between the maximum capacity of all the derivations and the total available discharge of the rivers, and that the difference between the capacity of canals in summer and their capacity in winter is 65 cubic metres. Both deficiency and difference should be remedied in order to use the maximum power of the canal; at the same time the natural loss should be taken into consideration. This can only be done by procuring to the Domanial network a larger supply from the Sesia and Ticino.

5.—Description of the Cavour Canal Works.

The derivation of the Cavour Canal is situated about 400 metres below the bridge thrown across the Po for insuring the traffic from Chivasso to the National Road, Turin-Casale. The supply to this derivation is insured by means of a temporary dam, most of which consists of big stones thrown across the river. It is made so to reduce the expenses to a minimum and to produce the least possible alteration on the regimen of the river. To this dam is adjoined at its left end an escape (submergeable in great floods), composed of thirteen arches each two metres wide regulated by simple free planks, of which the lower ones, however, are fastened by chains, so that in case of emergency all the planks, with the aid of a capstan, can be taken out at once. From the left flank of this escape the head sluice of the canal is retired for a distance of about 200 metres, and close to its right abutment a second escape of nine openings 1·50 metres wide and 3 metres high is built. This second escape is meant to exclude the excess water over the requirements of the canal as well as the solid matter that may be carried by the water, and for this reason its floor is made 0·30 metres lower than that of the head sluice.

The flooring of the canal above and for 14 metres below the head sluice was formed in the following way: the soil was first removed to

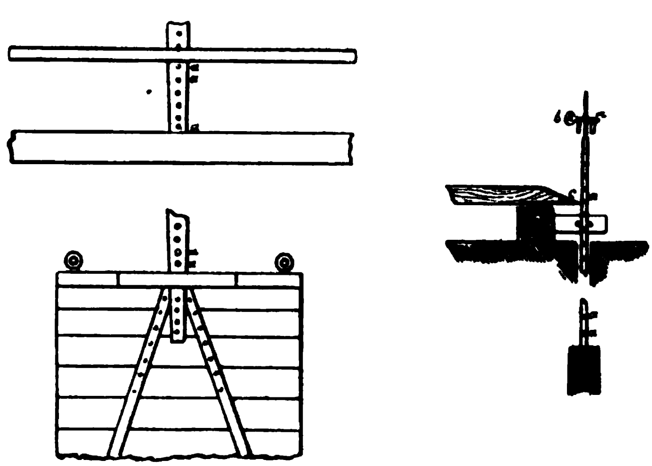
CAVOUR CANAL.

Head sluice and escape.

a depth of one metre below the proposed floor. The whole space was then driven with piles in lines along and across, 1·00 metres apart,

the piles being about 3·50 metres to 4·00 metres long, with their tops 0·15 metres below the canal bed. All the space between the piles was then rammed with concrete and their tops connected together by horizontal beams, forming a grilling. Over this was laid the pavement of granite slabs, about 1·50 × 0·75 metres in size and 0·15 metres thick, bound together by iron cramps.

The head sluice [the particulars of which are given in (Plate XI)] consists of twenty-one openings each 1·50 metres wide and 2·20 metres high, the piers being of granite 0·40 metre thick, and the opening covered with slabs of the same material. The openings are fitted with a double set of gates, and the cutwaters of the piers on the upstream side have grooves besides for stop planks. Owing to the height to which the river occasionally rises, it is necessary to make the head sluice 7·70 metres high from the floor to the roadway, or rather to the terrace above. This of course is an inconvenient height for pulling up the gates should they want repairs. The building has an under passage or storey running from pier to pier which also helps to strengthen and brace the whole. At one end is the house of the guard, at the other is an office, and the use of the covered bridge between is limited to the canal officials. At either end there is a flight of stairs running down to the lower story, which is 3·20 metres above the canal bed and 1·40 metres above the full water supply surface. But as it happens when the gates are closed and there is a heavy pressure of water above that some is sure to get through into this lower story, it is furnished with a shallow drain running along it and discharging at the ends.



The grooves in which the gates work go up to the level of this story only. Above it the piers are curved as it is shown on the plan, forming

as it were segments of the sides of a wall; and when a gate needs repairs it is raised to this level, the raising bar from its centre is taken off, a lever passed through two rings on its upper edge, and then it can be turned round out of the direction of the grooves, and drawn in between the piers to the platform within.

The gates are of wood firmly braced with iron. They have on each downstream side three little wheels resting on the granite grooves, to diminish the friction in raising or lowering them. They are raised by means of an iron bar $0 \cdot 11 \times 0 \cdot 02$ metre and about 5·50 metres long, firmly fastened to the centre of the upper edge of the gate and connected to the lower corners with diagonal bars to distribute the force.

This bar passes through to the upper storey, being kept in its place by little guide wheels. It is pierced with holes *aa*, 0·04 metres diameter and a distance of 0·05 metres one above the other, through which the iron point, *c*, of a crowbar is put when it is required to raise it and it is lowered down hole by hole, an iron key, *b*, being passed at the same time through another of these holes, and resting on two cross-bars to prevent its slipping down again One man works the crowbar, while another holds the key. By pulling the key out the gate falls at once, and this is important, as it is of consequence sometimes to be able to close the canal quickly. This arrangement is simple, and is the one generally employed in Piedmont as well as in Lombardy.

For the head sluice, as well as for the other works, there is an indicator of level put in communication with an electric bell placed in the sluice-keeper's house, which rings every time the water falls below the normal level, so as to warn the sluice keeper.

All the head sluices and escapes of the network of the Domanial canals are connected by telegraph and connected to the offices of the districts, as well as to the head office. The guardians are well acquainted with telegraphic work, and I saw in several places boys of not more than 12, the children of the guardians, carrying on this work for their fathers.

From its head sluice the Cavour Canal is directed towards the north-east after having run to the east on the alluvium of the Po for 4 kilometres. It crosses all the water-courses which tail into this river, divides the plain into two unequal parts, irrigating the lower, which is the larger of the two, and ending at the right bank of the Ticino in the territory of Galliate.

On my visit to the tail of the canal on the 3rd September, 1899, I noticed that it was not utilized for the last 4 kilometres above the Ticino and an earthen dam was thrown across the canal at this point.

The following table gives some details about the main canal and its branches:—

DESCRIPTION.	Length.	Bed width.	Depth.	Mean slope.	Discharge per sec.	
	Metres.	Metres.	Metres.	Metres.	Cub. met.	
Cavour Canal	82·00	20	3·20	0·36	40	
Farini Feeder to Cavour Canal..	3·20	32	2·20	0 32	70	
Montebello Canal	4·70	5	—	0·75	10	88
Quintino Sella Canal...	25·60	10	1·90	0·40	30	
Right Branch	13·50	5	—	0·30	6	
San Giorgio Canal	12·30	—	—	—	—	
Left Branch	35·00	7	—	0·40	20	
Vigevano Canal...	—	10	1·55	0·30	22	

On a length of 82 kilometres the Cavour Canal irrigates successively the territories of Chivasso, Verolenga, Saluggia, Livorno, Bianzé, Crova, San Germano, Santhia, Ballocco, Vallarboit, Greggio, Recetto, Biandrate, Vicolungo, San-Pietro, Mosezzo, Novara, Cameria and Galliate.

A feeder derived from the Dora Baltea in the Saluggia territory, under the name of Farini Feeder, gives to the Cavour Canal a discharge of 70 cubic metres in order to make up the normal discharge fixed at 110 cubic metres by the Act of Concession, the minimum discharge of the Po at Chivasso being only 40 cubic metres.

From its head sluice to the crossing of the raillway, Turin–Milan, the Cavour Canal supplies water to the existing canals which cross it, increasing their discharge and improving the quality of their water. These are the canals Neirolli, Carpeneto, Naviletto of Saluggia, Naviletto of Asigliano, Naviletto of the Tane, Ivrea and the Naviletto of Termine.

Past the Sesia the Cavour Canal feeds, and increases the discharge of, the existing canals, viz., Biraga, Cavetto Busca, Cavi, Zottico, Cattedrale, Nibbia, Panizzina, Dassi, Ospedale and Navelline.

At kilometres 57·50 is the offtake of the Montebello Canal, at kilometre 73·70, is that of the Quintino Sella Canal and at 78 is that of the Vigenano Canal, the last branch of the Cavour Canal taking just above the earthen dam situated 4 kilometres above the Ticino.

Since the first three years (1870 to 1872,), the effective discharge of the Cavour Canal has been fixed at 110 cubic metres per second down to the Cervo Torrent and at 90 cubic metres below the syphon under the Sesia.

The Act of Concession of the 25th August, 1862, had, in fact, fixed the volume of water to derive from the Po at 110 cubic metres per second. Consequently, the sections and slopes were made apportionate to this discharge on the whole length till the passage of the Elov

torrent, after which a discharge of 90 cubic metres was recognized to be sufficient down to the Busca canal. On the other hand, as it was expected that important offtakes would be established between the Sesia and this canal, the discharge below the Busca Canal was reduced to 50 cubic metres down to the Terdoppio torrent, below which the discharge was further reduced to 30 cubic metres down to the tail.

The low water[1] of the Po having proved insufficient to give the conceded volume of 110 cubic metres, it became necessary to take the deficient quantity from the Doro Baltea by means of a derivation (Farini Feeder) of 70 cubic metres.

On the table given below are shown the details of the sections and slopes of the canal in connection with the discharges in the different reaches.

The normal dimensions of the sections have been somewhat altered to meet local exigencies. Thus to avoid the difficulty which appeared from the very head of the canal having at that point a depth of 3·40 metres of water, the bed of the canal has been given, in the first kilometre, a width of 40 metres, and a slope of 0·50 metre. The sides in these parts were built of masonry and started with an inclination of $\frac{3}{1}$ and ended with $\frac{1}{1}$ slope at the close of the first kilometre. The canal does not get its normal bed-width of 20 metres till the 9th kilometre.

The section varies also at the passage, in aqueduct, or in syphon, of the valleys of the Dora Baltea, the Elvo, the Cervo, the Sesia, the Agogna and the Terdoppio; and the bed of the canal is lowered at the same time at these passages in order to increase the effect of the escapes adjoined to each passage.

CAVOUR CANAL, MAIN CANAL.	Length in kilom.	Disch. per second.	Bed width.	Height		Slope per kilometre.
				of water.	of berms.	
1st Reach:— From head to the Elvo	39·40	110	20·00	1·87 to 3·40	4·00	0·25
2nd Reach:— From the Elvo to Busca Canal	23·15	90	20·00	2·50 to 3·20	3·70	0·25
3rd Reach:— From Busca Canal to Terdoppio	11·22	50	12·50	3·00	3·70 to 3·50	0·25
4th Reach:— From Terdoppio to Ticino	8·45	30	7·50	3·00	3·50	0·25 to 0·20

[1] The low water of the Po in the hottest months, July to September, is such that it fell to 28 cubic metres in 1881, while the water of the Dora Baltea, abundant during the same period, could supply 90 cubic metres instead of 70 cubic metres.

The earthern sides, the slope of which was made $\frac{1}{1}$, have taken by themselves a $\frac{3}{2}$ slope after the passage of the water in the canal. These sides stand admirably in spite of the variations of water level occurring in the different seasons of the year. This is certainly due to the great radius given to curves which vary from 1,000 to 2,000 metres. The mean radius applied to curves of earthen sides is 300 metres.

M. Canavotto, the Engineer of the 1st section of the Cavour Canal, told me that the mean velocity of the current in the main canal varies from 0·80 to 0·90 metres. and at these velocities no silt is deposited in the bed of the canal nor does erosion takes place in the sides. He, however, added that when the velocity reaches one metre the sides are eroded, and for their protection he tried the dry rubble masonry, but without successful results. He, however, succeeded very well in using rubble simply thrown on the sides without order.

The constructions that the execution of the Cavour Canal has necessitated are extremely numerous and several of them, besides the head works already described, are very important on account of the large number of water-courses, rivers, torrents, roads, canals and trenches existing in the country and crossed by this canal.

Since the dimensions of the canal decrease as it goes off the head, and is divided naturally into four reaches, it was necessary to establish different types of construction for each reach.

First Reach.—From the head sluice to the Elvo: forty-five bridges of three arches for roads and paths, one bridge for the Milan–Turin railway, ten aqueducts, 128 syphons (26·9 mean length).

The service roads along the canal are 4·50 metres wide, crossing all the water-courses on bridges.

Several syphons are generally gathered in the same edifice; but when a water-course can be crossed by an aqueduct, the preference is given to it, being considered much less expensive.

Second Reach.—From the Elvo to the Busca Canal: twenty-two road-bridges, twelve aqueducts, sixty-nine syphons (28·40 metres mean length).

Third Reach.—From the Busca Canal to the Terdoppio Torrent: thirty road-bridges of two arches, thirty-six aqueducts of four arches and fifty-two syphons.

Fourth Reach.—From the Terdoppio Torrent to the Ticino: twelve road-bridges of one arch, three aqueducts of three arches and three syphons.

The total number of constructions on the whole canal, often grouped in twos and threes, are 316 edifices.

It is to be noted that as the third reach crosses the Novarese, where

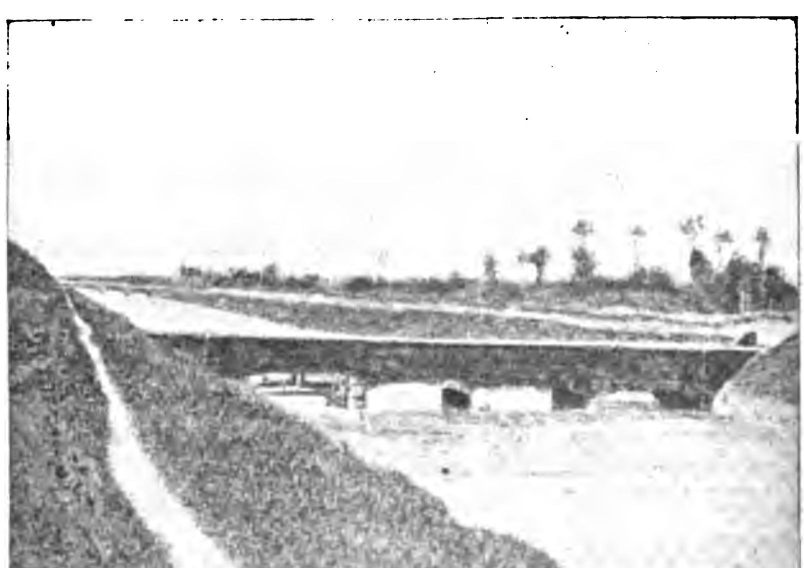
there are so many canals and trenches fed by springs (Fontanili), it has necessitated such a large number of constructions as above detailed.

Finally, the superintendence of the canal has necessitated the construction of eighteen two-storeyed houses, besides that built at the head sluice for the guardians.

As established, the Cavour Canal was meant to irrigate an area of 380,952 acres, but as a great part of its water, about two fifths, gives a supplementary quantity to several canals, the areas that these canals give water to ought to be added to the area commanded by the Cavour Canal proper.

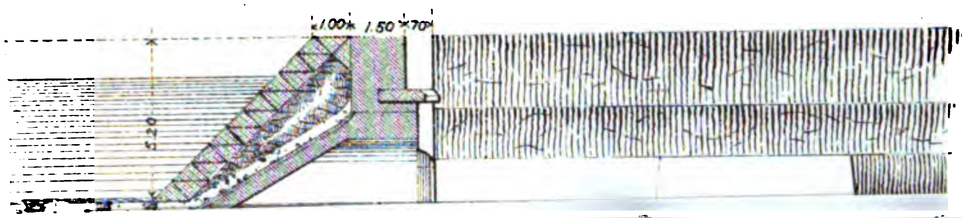
The works of great engineering interest on the canal, besides the head sluice, are the following:—The great aqueduct over the Dora Baltea in the 11th kilometre, the syphon under the Elvo in the 40th kilometer, the aqueduct over the Cervo, Roasenda, and Marchiazza, in the 47th, 52nd, 53rd kilometres respectively, the great syphon under the Sesia in the 57th kilometre, and the syphons under the Agogna and Terdoppio in the 71st and 76th kilometres. The whole course of the canal from the right bank of the Elvo to the left of the Sesia is especially interesting as it consists of a series of massive and important engineering works, aqueducts, syphons, embankments, and curves requiring very great skill in design and construction, as it has to face in quick succession five Alpine torrents past which it has been successfully carried.

CAVOUR CANAL.



Acqueduct over Dora Baltea.

The Dora Baltea aqueduct is 193·55 metres long and consists of nine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The Dora Baltea aqueduct is [illegible] metres long and consists of nine

A BAI
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arches, each 16 metres span. Full details of it are given in (Plate XIII). The foundation rests on piles, over which lies a bed of concrete enclosed on all sides in sheet piling. This bed goes down only 0·50 metres below that of the stream. At the two ends of the aqueduct the canal is carried in embankment for a total length of 2,150 metres. This embankment is revetted throughout with walls 1 metre thick at base, and with a batter of one-tenth in front. Behind this the crest of the embankment is only 3 metres wide and the exterior slope is $\frac{4}{3}$.

Just above the aqueduct there is an escape into the Dora Baltea, and another further up leading into the Po, about 4 kilometres from the head.

The Cervo, Roasenda and Marchiazza are crossed by aqueducts built on the same principle. The first, which carries a large volume is crossed by seven arches of 14·70 metres span and has revetted embankments at the two ends, 2,721 metres long. The Roasenda and Marchiazza are much smaller torrents and are crossed by three arches each.

The most interesting and difficult works on the canal are the syphons under the Elvo, Sesia, and Agogna. That of the Sesia is the largest and deserves to be described in detail. The torrent comes down with

CAVOUR CANAL.

Syphon under the Sesia.

a slope of 1 in 250 metres over a fairly well defined boulder bed, and the syphon has been constructed so as to allow 4,000 cubic metres of water to pass through it per second, the whole length of the syphon

being 265 metres. The bed of the canal is lowered 0·60 metres to pass under this stream, and the fall is carried far enough back to give room for an escape on the right bank with its floor flush with that of the syphon; by this means the latter can readily be laid dry during a canal closure. The syphon consists of five flattened vaults, details of which are given in (Plate XII). There is a reverse slope of one metre given to the floor of the syphon, contracting its area; and the canal, which has a bed slope of one metre in 4,000 and a depth of 3·20 metres, has below this point a slope of one metre in 2,912 and a depth of 2·60 metres, gradually assuming its former section after a length of 4,600 metres. The arches are 0·50 metre in thickness, overlaid (as is the invariable custom in all the arch works on this canal) with a thin layer of concrete. Above this a grating of timber bedded in concrete has been laid across the bed of the stream, and to this grating a decking of planks is screwed down over which the stream flows. The slopes at the two sides, which run for a considerable distance up and down the channel of the torrent, are protected by revetment of concrete masonry known as prisms. These are blocks of concrete about 1·25 metres long with a cross-section of an equilateral triangle, each side being one metre. To make a cubic metre of this material it requires about 0·80 cubic metres of gravel, 0·45 cubic metre of sand and 0·20 cubic metre of lime. The materials are mixed either in a wooden frame or in pits made in the ground and covered over with a 0·50 metre layer of earth; they remain thus buried for a year or more until they become hard and ready for use. When they are built into walls they present in the front alternating edges and bases; they are joined and pointed with mortar, and are found an excellent material of revetment for banks, spurs, etc.

Above the syphon, the course of the Sesia is regulated by a long series of spurs extending from both banks so as to bring it straight to the work. These spurs are built on concrete foundations retained by piling, and are of a very massive construction. The escape above the syphon consists of six openings, each 1·37 metres wide and 2·40 metres high, with grates raised in the same way as that described in speaking about the head works. The channel runs out into the Sesia below.

The Elvo, Agogna and Terdoppio syphons are all made on the same principles; that of the Elvo having into it a drop of 1·80 metres, and a width of 177·40 metres, and that of the Agogna having a width of 47·85 metres and merely the surface of the water lowered. The Terdoppio syphon is the smallest.

At each of the torrents, the Dora Baltea, Elvo, Cervo, Sesia, Agogna,

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and Terdoppio, there is an opening from the canal; but these openings play a far more important part than that of mere escape. As said before, the Cavour Canal, besides carrying irrigation into a new district, has for its object to supplement the irrigation already in existence. Consequently, it has very few, if any, distribution channels made directly from it to the west of the Sesia; but it supplies the numerous old canals which cross its course at those points, and not only these, but through its escapes into the above-named streams it keeps them supplied with water, which is taken into other canals by weirs further down in their course, so that these rivers are really made distribution channels.

Plate XIV, shows the method used for carrying out the system of feeding the old canals that cross the course of the Cavour Canal. In the 34th kilometer from the head of the latter, the Ivrea Canal is carried under it by a syphon of three vaults, each 2 metres wide and 1·25 high. Only a few kilometres above, this canal is fed from the Cigliano (Depretis) Canal, under which it is carried; and as it irrigates a large area near Vercelli, it was requisite to increase its supply and improve the quality of its water. Accordingly, an escape was made in the right bank of the Cavour Canal, consisting of six openings, each one metre wide. The water that passes these openings is received into a large chamber 39 metres in length, the lower end of which is barred by an overfall 9·00 metres long and 0·90 metre high having a wooden edge on its crest rising over it to a height of 0·12 metre. In the left downstream corner of the basin above this weir there is in connection with it a little chamber containing a water gauge, which is thus kept in perfectly still water and can be measured with great accuracy. The wooden edge over which the water falls makes the discharge corresponding to any height on the gauge to be known with tolerable exactness, and the guard, whose house is just on the other side of the canal, receives directions to regulate the escape gates so as to keep the water in the chamber at any given height.

At this point the water is sold to the Vercellese Irrigation Society, which will be spoken of further on. The normal quantity of water given from the Cavour Canal through the escape is 160 "Modules[1]" or 9·58 cubic metres per second.

The same method is also used for all the direct branches of the Cavour Canal, the most important of which are the Montebello, Quintino Sella, and Vigevano Canals.

Before leaving the crossing of the Ivrea Canal I must restate that

[1] A "Module" is equal to 59·88 litres per second.

this canal was enlarged in 1899 from the point of its meeting with the Cigliano Canal, down to the Cavour Canal, so as to be able to give to the Cavour Canal an extra supply of 30 cubic metres per second from the water of the Cigliano. Consequently a junction was made between these two canals just above their meeting which was provided at its tail into the Cavour Canal with an eight-opening regulator to regulate the supply. Another regulator of four arches was constructed on the Ivrea Canal between the above-mentioned junction and the syphon carrying the Ivrea under the Cavour Canal also for regulating the supply of the Ivrea Canal. The span of the openings in both regulators is 1·20 metres.

6. *Farini feeder to the Cavour Canal from the Dora Baltea.*—The discharge of the Cavour Canal, as fixed by the Act of Concession of the 25th August, 1862, was 110 cubic metres per second, to be taken from the Po with the obligation to provide for any deficiency below this quantity from the Dora Baltea. Originally, the minimum discharge of the Po was estimated at 92 cubic metres, while Lombardini and Porro made it 32 only, and often it was actually not more than 40 cubic metres (it even fell in 1881 as low as 28 cubic metres), thus leaving 70 cubic metres to be provided from the Dora Baltea. Therefore the Farini Feeder was made in 1868.

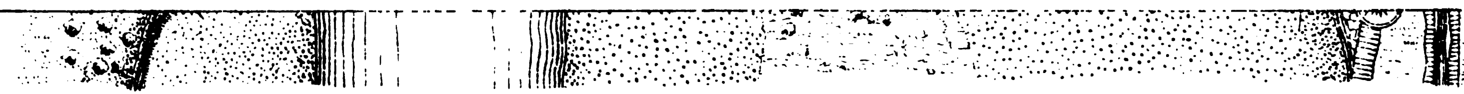
The following remarks are quoted in summary from a pamphlet written by engineer Benazzo on the work.

It was shown from measurement made in the summer of 1867, a year of extreme drought, that the Dora Baltea still discharged 110 cubic metres per second, below the regulating weir of the Canal del Rotto, that is after having fed all the Domanial, Communal, and private canals dependent on it. There was no doubt, therefore, that it was possible to get from it the 70 cubic metres deficient for the Cavour Canal.

The water level of the Cavour Canal at the aqueduct carrying it over the Dora Baltea is R.L. 173·00 and the water level of this river in summer at the above-named aqueduct is R.L. 165·89 or 7·11 metres below that of the canal. This difference divided by 2·80, which is the slope per kilometre in this part of the river, shows that at about kilometre 2.540 above the aqueduct, following all the sinuosities of the stream, the water level of the Dora is 173 metres, and in going up still 500 metres to the railway bridge, near which the feeder was proposed to take off, it was found that the summer level of the Dora Baltea was 174·38. This figure showed the possibility of introducing the water derived from the Dora into the Cavour Canal in the shortest possible distance.

FARINI FEEDER

PL. XV.



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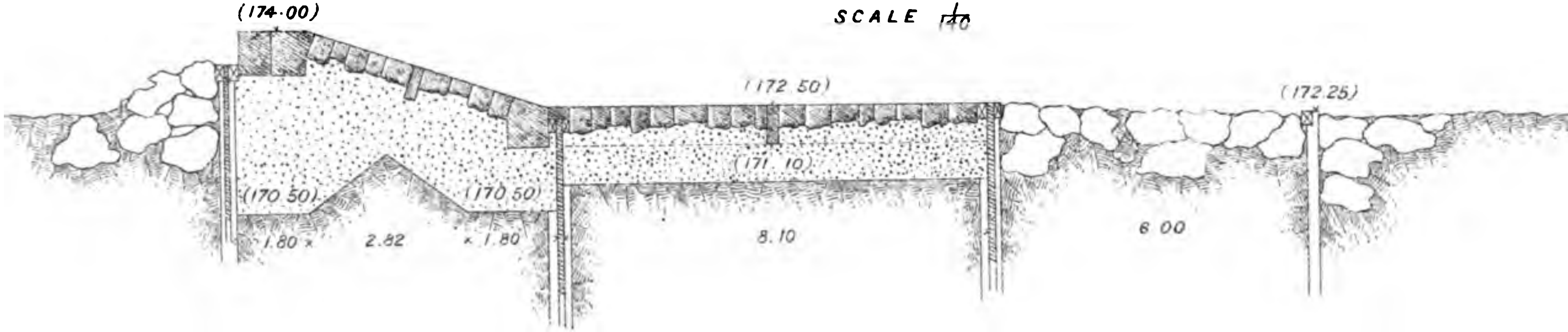
SCALE $\frac{1}{40}$



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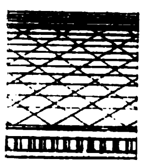


The position of the derivation below the railway bridge being thus fixed, the principal precaution was to select the line of the feeding channel so as to be entirely within soil, or at least to have its head below country level. This had in fact been done, but owing to the low level of the country in the last 500 metres, a drop of 1·61 metres was made in the bed. This drop had also two other ends in view:

1st. To avoid giving an excessive slope to the bed, had it been made flush.

2nd. To form a depositing basin for the materials which the summer water of the Dora Baltea carries in large quantities and which are less useful to the land than those carried by the Po water.

The slope of the bed of the feeder was made 0·317 metre per kilometre; it is therefore less than that of the Cavour Canal which is 0·36 metres, and thus the silt deposit is avoided in the Cavour Canal because of the less slope of the feeder.

The total length of the feeder is 3,153 metres and the level of the water below its head sluice was fixed at R.L. 174·00 and the depth of water 1·80, consequently from the formula of the uniform motion with Eytelwein coefficient it results that the mean width is 33·80 metres, and in making the side slopes $\frac{1}{1}$ the bed width was fixed at 32·00 metres.

The mean velocity was calculated by the same formula which gave

$$V = 1{\cdot}15 \text{ metre.}$$

The bed of the feeder immediately below its head sluice was fixed at R.L. 174·00—1·80 = 172·20.

As the required discharge is 70 cubic metres per second, the head sluice was made of eighteen openings of the dimensions shown on Plate XVI.

If S is the area of one of the eighteen openings below the downstream water surface, x the difference of level between the upstream and the downstream sides of the head sluice, D the share of one opening in the total discharge (3·888 cubic metres), and making the cœfficient of reduction $m = 0{\cdot}95$ the following formula,

$$D = mS\sqrt{2gx}$$

gives

$$x = 0{\cdot}12 \text{ metre.}$$

This means, that in order to have a discharge of 70 cubic metres in the feeder, the depth of water above the floor of the head sluice at the downstream side being 1·80 metres that on the floor at the upstream side should be 1·92 metre. That is to say, the minimum depth of water on the crest of the weir in the river should be 0·12 metre. This

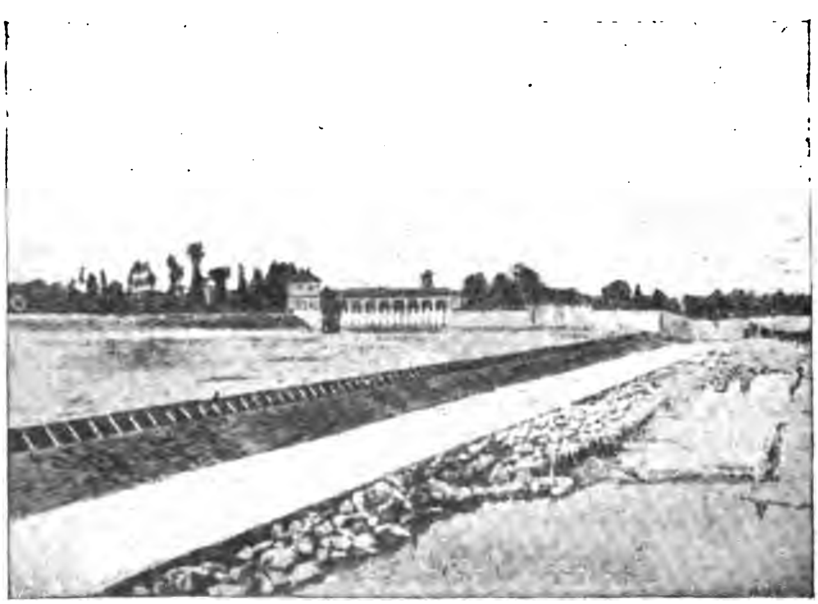
condition is satisfied, as from calculation it results that in order to get such depth of water on the crest of the weir a discharge of 16·00 cubic metres should be escaping over it.

Therefore the total minimum discharge of the Dora Baltea above the offtake of the Farini feeder will be sufficient if it is only 86 cubic metres, and as we have seen before that the discharge of the Dora Baltea at this point is never less than 110 cubic metres we conclude that the feeder will always get its required discharge.

Under these conditions it was found sufficient to put the crest of the weir at R.L. 174·00. This weir is normal to the current and is 200 metres long.

Between the head sluice, which was made on the same principles as that of the Cavour Canal, and the weir, there has been constructed an escape composed of two arches; the larger of the two is divided into two parts of a total span of 14·40 metres by a submergible pier 2·8 metres thick, whose top is at R.L. 174·00. The two parts of this arch are regulated by gates called "Marinières." The smaller arch of the

FARINI FEEDER.

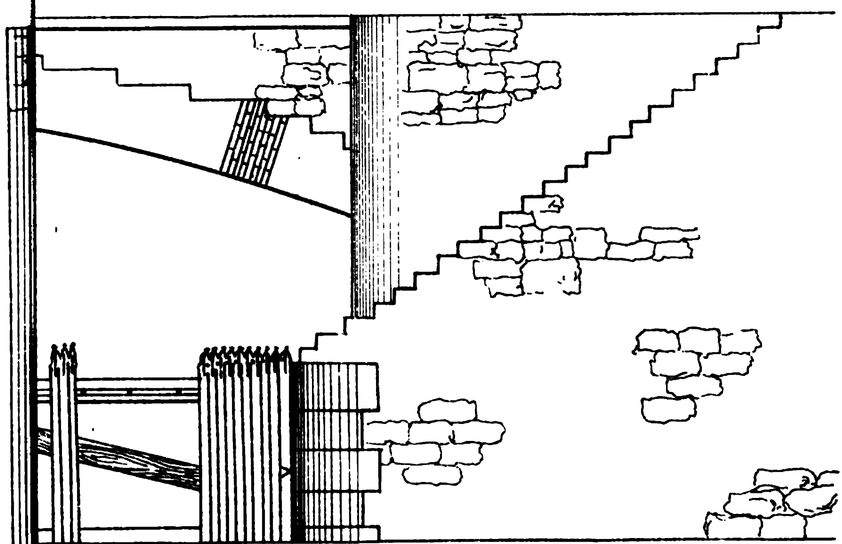


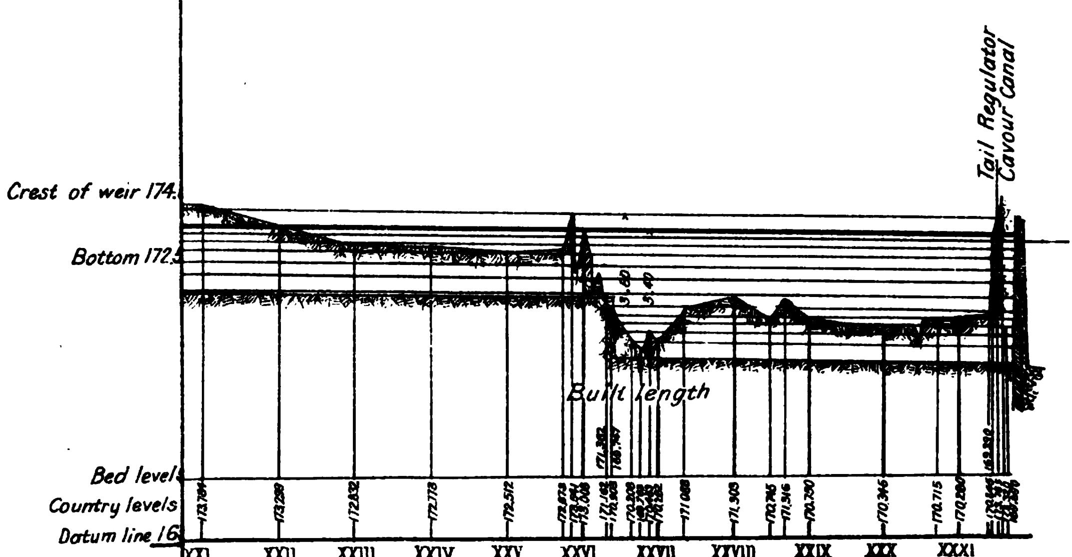
Head sluice.

escape is in its turn divided by piers of granite, into four parts of a total span of 5·60 metres. The sill of this arch is at R.L. 172·00, the springing at R.L. 174·30, the intrados at R.L. 175, and the chord is 6·80 metres.

PL. XVI bis.

SCALE $\frac{1}{100}$





Let us see now the influence of these works on the regimen of the river in flood time.

The maximum discharge of the Dora Baltea in flood time is 3,150 cubic metres per second, and the water level at the site of the weir before its construction during the same period was 176·20.

Since the construction of the works the flood discharge of the river is got rid of in the following way.

The Farini feeder is given the required discharge only, and the rest is escaped partly over the weir and partly by the escape left fully open. The discharge of the different openings are found by the two following formulæ:—

(*a*) Discharge of a free weir,

$$D_1 = 2{\cdot}95 m l x \sqrt{x}$$

where,

D_1 Is the discharge per second of the free weir.
m Coefficient of reduction 0·70 metre.
l Length of the weir.
x Difference of levels above and below the weir.

(*b*) Discharge of a submerged opening,

$$D_2 = mS\sqrt{2gw}$$

where,

D_2 Discharge of the opening.
S Sectional area of the opening below the downstream level of water.
g Gravitation coefficient = 9·8088.
m and x have the same signification as in (*a*).

According to the nature of the different openings through which the flood discharge is got rid of, the following quantities were calculated:—

1st. Discharge of the weir,

$$D_1 = 2{\cdot}952 \times 0{\cdot}70 \times 200x\sqrt{x}.$$

2nd. Discharge of the head sluice,

$$D_2 = 0{\cdot}95 \times 400\sqrt{2 \times 9{\cdot}8088 \times x}.$$

3rd. Discharge of the two openings to which the gates, "Marinières" correspond,

$$D_1' = 3{\cdot}952 \times 0{\cdot}70 \times 14{\cdot}40\sqrt{x}.$$
$$D_2' = 0{\cdot}70 \times 56{\cdot}90\sqrt{2 \times 9{\cdot}8088 \times x}.$$

4th. Discharge over the pier existing in the middle of the large arch of the escape (plus that flowing on the right side over the three last steps of the stair),

$$D_1'' = 2{\cdot}952 \times 0{\cdot}70 \times 2{\cdot}80\sqrt{x}.$$
$$D_2'' = 0{\cdot}70 \times 5{\cdot}04\sqrt{2 \times 9{\cdot}8088 \times x}.$$

5th Discharge of the openings of the smaller arch of the scape,

$$D_2''' = 0{\cdot}95 \times 15{\cdot}29\sqrt{2 \times 9{\cdot}8088x}.$$

Adding all the above discharges and making the sum equal to 3,150 cubic metres, we get the following equation of the 3rd degree:—

$$x^3 + 7{\cdot}22x^2 + 13{\cdot}05x = 49{\cdot}30.$$

whose applicable root in the present case is,

$$w = 1{\cdot}73 \text{ m}.$$

Therefore the highest water level in flood time above the weir will be,

$$176{\cdot}20 + 1{\cdot}73 = 177{\cdot}93.$$

In flood time the slope of the Dora Baltea per kilometre near the railway bridge is 3·36 metres, therefore the back water of the weir would go only 800 metres upstream.

In consideration of this, longitudinal protective banks were made between the railway bridge and the weir and their crest was put at R.L.179·00 metres. Above the railway bridge nothing was made, the banks of the Dora being high enough.

The feeder was also provided with a tail regulator to be used in case of emergency. Plate XVII shows the design of a road-bridge built on the feeder, which I especially give as an exemple representing the style of bridges employed on the Cavour Canal and its branches.

The cost of the feeder and its masonry works was estimated at £E.23,073, but the actual cost was £E.45,461.

Since the first year of its use, the silt of the Dora invaded this feeder, depositing on the whole line a layer of more than 0·50 metre in thickness. This was caused by the affiux of the Cavour Canal water into the feeder water owing to the very short length of the feeder and its nsufficient slope.

Notwithstanding the 40 cubic metres from the Po and the 70 cubic metres from the Dora Baltea, the Cavour Canal always lacked 30 cubic metres on its 90 cubic metres capacity which is obligatory below the Sesia passage. To make up this deficiency we have seen that the Ivrea Canal was enlarged in 1899 so as to give to the Cavour Canal an extra quantity of 30 cubic metres from the Cigliano Canal.

7.—Association of Irrigation on the West of the Sesia.

Previous to 1853 the existing canals were not gathered in one service. The domanial waters were in confusion with private waters. The measuring of discharges was unknown, moreover, the method of irrigation "a bocca libera," with payment "in natura" was prevailing. Through the influence of Count Cavour and the initiative of the Engineer Carlo Noé, all the propritors on the west of the Sesia founded

a great Association of Irrigation which, on the 1st January, 1854, by virtue of the law of 3rd July, 1853, began to work with a discharge of 23·2 cubic metres, which was gradually doubled. Now 44 "Consortii" with 107,142 acres are united.

The association receives now the following quantities of water per second:—

Name of Canals.	Summer Supply.	Winter Supply.
	cub. met.	cub. met.
Canals derived from the Dora Baltea	30	10
Canals derived from the Elvo and Cervo Torrents...	5	5
From the Cavour Canal	15	10
Totals... ...	50	25

In its turn the Association distributes these quantities among the different "consortii" against prime cost, augmented by the proportional share of the common expenses.

By this way of dealing the prices for the equivalent crops and areas were often very different. It was then agreed that all the irrigation service should be done through the Association, and all expenses should be equally distributed on the crops and areas.

The water supplied to the Association by the Domains is in every case conveyed to a single canal entirely in the hands of the Association. The water is distributed from the canal to the branches by "Stramazzo[1]" and then to the private branches. If the quantity of water supplied to the Association decreases the decrease will be proportional for all.

The water power remains Domain property. It is employed here for turning machines used for grain thrashing and rice peeling. This water power is given gratis to the Association for their own service.

The canals are dried once a year, in April, for clearance, and all the works of the Association are put by the Domains under controllers, in virtue of the Convention already mentioned. To this Convention is attached a list of all rights upon the Domanial canals handed over to the Association which they shall respect.

The proportions of rates per watering consented to by the Association are fixed as follows:—

Arable lands	1
Grass lands	3
Rice fiields...	7

Any member of the Association owing water must cede it to the Association when they require the use of it; in return, he has the right

[1] Free fall.

to take Domain water with the reduction of one-fifth on the price agreed upon.

The management of the affairs of the Association is carried on in the following way :—

Each "consortium[1]" appoints a delegate who has one vote. Ten of these delegates are chosen for directing the general business of the Association.

The committee of superintendence is also chosen from the delegates, and consists of five members.

Differences are settled by arbiters. Any member committing any of the following misdemeanours pays into the treasury of the Association a fine varying from £E.0·400 to £E.2·000;

(*a*) Non-execution of the orders of the direction for the systematization and adoptation of the canals or of the lands.

(*b*) Modifying the arrangements of the administration relating to conveying, distributing, dividing or collecting the water.

(*c*) Altering the constructions, the bed or the side-slopes of the conducting canals or distributaries.

(*d*) Taking water from the canals for his own profit or for the benefit of others.

(*e*) Causing or abetting the loss or deviation of the water to the detriment of the Association.

Any member of the Association tampering with area irrigated to more than 3% pays £E.1·000 as penalty per acre, besides the price of the water and the expenses of the verification.

The member who does not sow rice on his land comprised within the zone alloted for this culture, must pay the same price as if he had sown rice, and cannot pretend to any idemnity for damage caused him by the adjacent water.

Endeavours to unite all the landowners using Domanial water and whose lands are situated between the Sesia and the Ticino were made but up to present they have not been successful.

Plate IX bis is a map of the plain of Piedmont between the Po and the Alps, the different systems of irrigation being shown by different colours.

8.—Water gauging and Tariffs.

The gauging of the discharges in large canals is a simple matter. It is done by fixing marks on water gauges. For smaller quantities modules are employed under the name of "a bocca tassata" that is

[1] A "Consortium" includes the landowners of a community.

openings of determinate form obligatory for all the landowners (see description in Chapter VIII).

In case the consumption of water is not normal and the cost of water is a high factor in the exploitation of land, the supply is made "a bocca libera." This way is continued until the lands improve and the consumption of water is naturally diminished, or until the landowners unite in association and enjoy in common, large quantities of water; then the supply "a bocca tessata" is adopted.

The prices for water often vary. The following is the latest tariff sanctioned by the Ministerial Order of the 22nd December, 1876 which is still in force. The price for each "Modulo Italiano"[1] (100 litres), of summer water is £E.88·461 per annum. This price is reduced by the Administration of the canals to £E.57·692 in the case of landowners formerly taking water by old contract through branches of their own.

A reduction of 20% is further granted to lands which have never been previously irrigated; this continues for the first three years only.

In special cases the Administration can supply water "a bocca libera," the surplus water must, however, return to Domains. In this case the prices per acre are :—

For rice	£E.	1·615
For meadows	"	0·969
For each watering of maize and similar crops	"	0·242

These water supplies vary with the quantities of available water in the rivers and supplied to the canals.

For winter irrigation the price per "modulo Italiano," is £E.6·923; for ice-covering of the meadows the land-owners pay nothing; the industrials can for the same purpose receive water at £E.0·384 per 1,000 square metres of land which come under water.

When the discharge of the canals allow, extra water can also be given at £E.1·538 per "modulo" and per diem.

For water power, which is considerable in the canals, the price per H.P. per month is reckoned at the rate of £E.0·192. In case this water is necessary for agriculture, it is returned to the Domains Canals in suitable places.

For other purposes than agriculture, industrial for instance, the prices vary in the different localities according to their commercial importance and the number of their population, from a maximum of

[1] The "Modulo Italiano," which will be described in Chapter VIII, is different from the "Modulo Piemontese," the value of which is 59.881 litres.

£E.3·846 to a minimum of £E.0·769 per theoretical H.P., reckoned on the difference of level between the upstream and the downstream sides of the motors.

Wherever the drainage water is useless to be re-employed for irrigation, the land-owners pay for getting rid of it.

In time of scarcity of water, as in 1893, regulations for a just water distribution on the area of 380,000 acres were absolutely necessary. A proportional reduction of the supply was made to all. This would, however, tend to decrease the outturn in some places, while in others, where springs exist, the outturn would not suffer, but the Administration always attemps to take into account this fact.

The daily changes in the water levels of the different rivers which feed the Domanial canals, continually oblige the Administration to modify the water distribution. The orders for modifications are naturally issued by the head office of the Domains of Turin.

In case of scarcity of water, every body is dissatisfied, and in the hope that the loudest howler will get the water first, all of them cry, and their claims are endless. In 1893 the people induced their representatives of the House of Deputies to interplead the Government on the subject and the result was the nomination of a commission to inquire locally. This commission could find nothing against the Administration.

9.—Duty of the Water.

The duty of the water varies according to the nature of crops and land. In Vercelli, where a great variety of lands exist, two-fifths of the total area is devoted to rice, three-tenths to grains and maize, and three-tenths to grass. The mean duty per acre per second is 1·05 litres. In Novara it is 1·26 litres. In Lomallina and other places along the rivers there are such great differences in the natures of the soil that it is impossible to give a mean figure. For rice crops the duty of water varies from 2 to 5 litres per acre per second.

10.—Private Canals.

Everywhere among the Domain canals there are private systems of irrigation which are often supplied with water by turns. The water prices are variable and are generally high on account of the rice canals.

In the rice fields where no irrigation by rotation is possible the supply is given by free openings. The payment for the water is usually made in kind ("in natura"), varying from one-fifth to one-third of the crop.

11.—Statistics.

The extent of the Domanial canals' network, their revenue, and the available water power are given in the following statements:—

Groups of Canals.	Length in Kilometres.			Totals.
	Main Canal.	Branches.	Secondary Canals.	
Canal Cavour and Farini Feeder... ...	85·453	78·712	81·283	245·448
„ Ivrea	73·920	37·619	167·283	278·821
„ Depretis (Cigliano)	31·371	0·370	6·500	38·241
„ Del Rotto	11·960	97·667	162·749	272·376
„ derided from the Elvo and Cervo.	38·733	1·050	46·176	85·959
„ Busca	58·000	—	69·170	127·170
„ Rizzo-Biraga	59·000	—	21·650	80·650
„ Sartirana	65·057	14·858	113·293	193·208
Dispersed groups	7·400	27·000	71·950	106·350
Totals... ...	430·894	257·276	740·053	1428·223

Below are also given the figures relating to two canals belonging to the Domains, but situated on the right side of the Po, viz., Canals Gazelli and Lanza or Casale.

Canals.	Length in Kilometres.			Totals.
	Main Canal.	Branches.	Secondary Canals.	
Canal Gazelli	15·316	—	—	15·316
„ Lanza	16·780	10·150	3·850	30·780
Totals... ...	32·096	10·150	3·850	46·096
Total for the left of the Po as per previous statement	430·894	257·276	740·053	1428·223
Grand Total for all the Domanial canals.	462·990	267·426	743·903	1474·319

Available Water Power.

Groups of Canals.	Theoretical number of H.P.	
	Summer.	Winter.
Ivrea Canal and branches in Novara...	665	388
Depretis Canal and branches in Novara	1,485	573
Quintino Sella and branches in Novara	3,736	4,932
Quintino Sella and branches in Pavia	2,229	1,956
Sartirana and branches in Pavia...	426	426
Totals...	9,541	8,275

Mean Yearly Gross Revenue for the Years 1886, 1887, and 1889.

Canals.	Revenue for perpetual concession.	Temporary Contracts for Irrigation.		Water power for		Rent for Mills.	Diverse Revenues.	Totals.
		Summer.	Winter.	Industry.	Agriculture.			
	£E. M.	£E. M.	£E. M.	£E. M.	£E. M.	£E. M.	£E. M.	£E. M.
Cavour Canal	—	32,361·745	942·771	178·037	142·994	—		33,605·547
Quintino Sella branch	—	5,039·584	589·513	2,129·304	16·406	—		7,774·807
Mortara sub-branch	—	3,569·940	316·883	12·431	9·211	—		3,908·465
Pavia sub-branch	—	3,800·191	456·217	45·831	0·751	—		4,302·990
Canals derived from the Dora Baltea ...	—	10,192·536	11·783	139·329	—	2,880·656		13,224·304
		—	—	—	—	—	1,282·623	1,282·623
Canals derived from the Elvo and Cervo.		1,243·298	—	531·403	—	759·089		2,533·790
	3,878·546	—	—	—	—	—		3,878·546
Busca Canal		6,141·388	286·584	—	62·395	139·885		6,630·252
Rizzo-Biraga		7,246·687	792·958	—	43·422	518·362		8,601·429
Sartirana		8,383·879	498·949	—	53·092	322·365		9,258·585
Lanza	—	3,315·359	32·146	957·902	10·424	—		4,315·831
Gazelli...	—	—	—	—	—	278·461		278·461
Totals...	3,878·546	81,294·607	3,927·804	3,994·237	338·695	4,899·118	1,282·623	99,615·630

12.—Canals on the right side of the Po.

On the right side of the Po, and deriving their water from it, there are two canals, Gazzeli and Lanza. Both of these belong to the Domains and irrigate lands on a small scale; the tracts they have to irrigate are almost entirely deprived of water.

The head of the Gazzeli Canal is in front of that of the Cavour Canal and that of Casale is situated just above the town bearing that name.

As the works on these two canals present nothing interesting, I shall not enter into details about them.

13.—General Administration of the Domanial Canals.

Administration and management of the Cavour Canal:—

After the publication of the Act of the 16th June, 1874 (No. 2002), and the Procès-verbal for the taking over of the Cavour Canal and annexes was signed, a Royal Decree dated the 6th July of the same year was issued fixing the necessary prescriptions for the management and maintenance of the works. On the 9th July the appointment of the technical and administration establishment, the division into districts, and the assignment of their head-quarters, took place.

The regulation of the 6th July, 1874, was however amended later on by a new Royal Decree issued on the 27th April, 1890.

The management of the Cavour Canal net-work, which is under the authority of the Ministry of Finance, has its head-quarters at Turin. It is composed of the following:—

(*a*) A central office composed of an administrative, a financial and a technical service, and the archives.

(*b*) Separate technical offices in the districts.

(*c*) An establishment of "Custodi" or guards.

At the head of the administration is placed an Administrator General, who is appointed by the King on the proposal of the Minister of Finance after having consulted his colleague of the Public Works. With the assistance of the above-mentioned establishment he manages the service of the Domanial canals in Piedmont and has the power to correspond with the sub-prefects and tax-officers. He is responsible for the proper carrying out of the administration, and can transfer or suspend the employés, fill vacancies, and can at any time, except between March and September, grant thirty days' leave. He cannot, however, take any measure against the employés belonging to the "Genio Civile" corporation without consulting the Chief Engineer.

The direction of the technical part of the administration is performed by a chief engineer, who is directly subordinate to the Administrator General. He is appointed by the Minister of Public Works after consulting the Minister of Finance. The remaining technical establishment, detached from the "Genio Civile" corporation, are also appointed by the Minister of Public Works.

The head-quarters of the district technical offices are fixed, where the Administrator General proposes, by the Minister of Public Works after agreement with the Minister of Finance. At present there are five offices—at Chiavasso, Vercelli, Novara, Mortara and Candia (Lomellina). Each office is directed by an engineer, and the districts are subdivided into sections, at the head of which are often placed "aiutanti," or assistants.

Besides the chief engineer there are, at the head office, at Turin, two engineers and two assistants. The administrative establishment is composed of one director, one secretary, one under-secretary, one inspector, one sub-inspector, one cashier-accountant, two book-keepers, two accountants, one archivist, three expeditors, three clerks and three office waiters. For carrying on the service in the districts there are four district engineers, two other engineers, six overseers, four assistants, three receivers (collectors), eight chief canal guards, and eighty canal guards. Sometimes these guards are increased in number by temporary men.

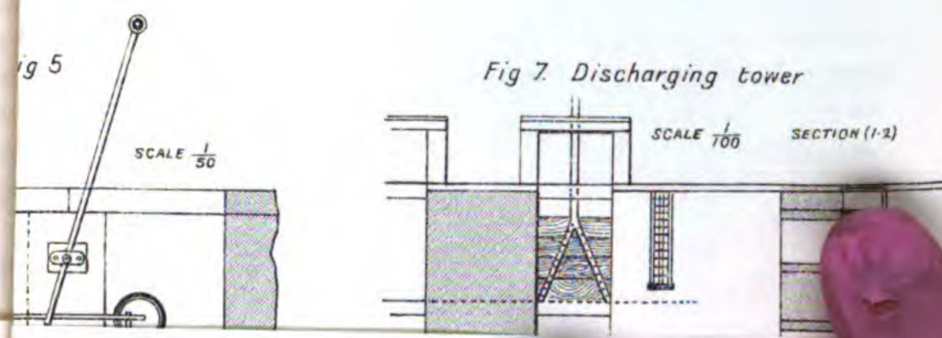
The salaries and the travelling expenses of the establishment belonging to the "Genio Civile" are paid by the Ministry of Public Works, all other expenses of the Administration are incurred by the Ministry of Finance. The revenue of the canals is collected by the collectors of the direct taxes, and sent by them to the head office of the canals at Turin.

The general regulation of the accounts of the State are in force here also. The Administrator has only the superintendence of small works, the conclusion of contracts for the execution of works or supply of the materials not exceeding £.E.307·600, and the conclusion of water contracts within same limits.

The daily superintendence of the works and the distribution of water are performed by the canal guards and the chief canal guards. The guards are obliged to keep pocket registers, on the first page of which are inscribed the name, the date of entrance in the service, and other necessary information. The other contents of the book are: the regulations of canal guards, an extract of the general regulation of the irrigation canals, an extract of the code on the duty of the sergeants of justice, and a model of a procès-verbal of contraventions. Besides

PL.XVIII.

ANTHIA



been described.

that, the register also contains a statement of the contraventions, punishments, payments received, rewards, and objects in his charge. The chief guard can annotate these books in passing by.

By the regulation of the 27th April, 1890, the guardianship of the canals is regulated. The usual name of the chief canal guards and canal guards are "custodi" and "sotto custodi." The "custodi" and "sotto custodi" form the real superintending establishment belonging to a large body appointed by the Minister. Each "sotto custodi" has from 3 to 4 kilometres of canal to superintend. The assistants, "ausiliari" are appointed by the Administrator on the proposal of the Chief Engineer. The "custodi" and "sotto custodi" are to see about keeping exact water levels at the points of water distribution, prevent the stealing of water from canals and any excavations on canal properties.

14.—Hydrometric Station of Santhia.

In view of public interest as well as of their own, the Administrators of the Domanial canals felt a long time ago the necessity of consulting the experimental science to give them surer rules for valuing the discharges of the different systems of derivations used on the network of the Cavour Canal and its dependencies. They knew that they could not accept the mean coefficient which experience had assigned for very small discharges and use it for big discharges. Moreover, they knew that they must take into account many circumstances that have great influence in practice for which they have no data from direct experience.

For these reasons a project was elaborated by Professors Dominico Turazza and Nazzani and the engineers Susinno Marchetti, Colli and Tronconi, for the erection of an experimental hydrometric station at Santhia, for guaging big discharges and making varied hydraulic experiments on a scale much larger than any that had hitherto been made in any part of the world.

It has already been stated how the Cigliano Canal escapes the greater part of its water into the Elvo torrent. This water passes afterwards to the Cervo torrent, then to the river Sesia and finally arrives at the Sartirana Canal, after having run for not less than 30 kilometres on a river bed, which is for the greater part of an absorbent nature. The project carried out in March, 1899, for utilizing a part of this escaped water by carrying it past the Sesia through the Ivrea Canal to make up the 90 cubic metres necessary for the Cavour Canal, has already been described.

The hydrometric station to which I devote the following page has been placed near Santhia on the Cigliano Canal at about 50 metres below its junction with the Ivrea Canal.

Fig. 1, Plate XVIII, shows the hydrometric station on a small scale, and gives an idea of the purpose for which it has been erected.

Head Sluices.—Two distinct head sluices Π and π are built in the vicinity of Santhia on the right bank of the Cigliano Canal about 30 metres apart, and at 50 metres below the junction of this canal with the Ivrea Canal.

The two head sluices represent two of the five principal types of head sluice actually in use on the Cavour Canal. The larger head sluice is made for a maximum discharge of 12 cubic metres, and the smaller for a maximum discharge of 3 cubic metres per second.

The larger head sluice has a total width of 9·15 metres and is divided into six openings 1·245 metres each, separated by stone piers 0·28 metre thick. Its sill is raised 0·90 metre above the bed of the canal, the depth of water on this sill is kept at 1·63 metres and the admission of the water is regulated by screw doors.

The smaller head sluice has a total width of 4·14 metres and is divided into three openings each 1·10 metres wide provided with screw doors and separated by piers of 0·28 metre thickness. The sill is 0·87 metre above the bed of the canal and the maximum depth of water on the sill is 1·66 metre.

Canals and Basins.—For the better understanding of the arrangement of the different canals and basins which follow the two above-mentioned derivations, it is necessary to explain, in detail, the priucipal purpose for which the station was constructed. This was, as already said, for the exact determination of the discharges of the different sluices actually in use on the Cavour Canal. The system most generally used by the administration of the Canal Cavour network is that of the free overfalls, "a stramazzo." In general the edifice of derivation consists of—

1. A sluice of extraction on the bank of the feeding canal.
2. A masonry channel, of a variable length—5 to 6 metres—partly covered by a bridge for the service road which runs parallel to the Cavour Canal.
3. A basin whose extremity is the "modellatrice" overfall which serves to measure the water spent.

The length of this basin is usually double its width which in its turn is double the width of the head sluice.

If there is any reason for making this basin long it should not be

made more than four times the width of the head sluice. But it is often very difficult to make the basin this length. The principal difficulty is the expense that has to be incurred. But there is no doubt that in the basins that are too short the water forms in entering them a current in the middle only, leaving the water on the right and left nearly stagnant instead of expanding and communicating the movement to the whole liquid mass in the basin. In such basins it may be useful to introduce some obstacles for forcing the current to break and the water to deviate laterally.

On the contrary there are cases where one can dispose of a certain length. In such cases it is useless to make the upstream wall of the basin and it is sufficient to construct a funnel between the place and the door of the head sluice.

The arrangements adopted for the cases of big dischargesup to 12 cubic metres per second and of small discharges up to 3 cubic metres per second are the following:—

Experimental Basins for the large Derivations.—To the large head sluice follows a basin V, whose bed is horizontal, 9·15 metres wide and 10·80 metres long, crossed by a three-arched bridge for the passage of the communal road that runs parallel to the Cigliano Canal. After a drop of 0·40 metre a second basin V′ follows which is 15 metres wide, 19·90 metres long, with a horizontal bed which is followed after a drop of 0·27 metre by another basin V″ of equal dimensions and with horizontal bed also. After another drop of 0·27 metre there comes a contracting junction 15 metres long which diminishes in width till it becomes 6 metres wide only. This width is also given to the canal *cc* which conducts the water to the measuring basin, or to the escaping channel, as will be seen further on.

At the beginning of the canal *c* there is an iron girder bridge L, 3 metres roadway. To the right of the three basins V,V′,V″, are three wells *i*, *i*, *i*, each communicating with one of these basins and used for hydrometers or guages.

The "Modellatrice" overfall for measuring the discharges can be placed either at the end of the basin *v*′ or at that of the basin *v*″, and experiments can also be made in the case where the basin that precedes the "Modellatrice" has a length double that used on the Cavour Canal.

Experimental Basin for the small Derivations.—The extraction head sluice for the small discharges is followed first of all by a channel *v* 4·06 metres wide and 10·50 metres long, having a horizontal bed crossed by a single-arch bridge for the service of the above named communal road. After the channel comes a basin *v*′ 4·94 metres wide, 12·5

metres long, whose bed commences at the same level as that of the channel and slopes with a total fall of 0·50 metres. Then comes a second basin v'' 7·50 metres wide and 16·00 metres long with the absolute slope of only 0·04 metres on the total length. All these dimensions are like those of the derivation which feeds the Asigliano Canal. The "Modellatrice" overfalls for measuring the discharges can be, at the will of the experimenter, placed at the ends of the three above-mentioned basins, and for that purpose the three wells i', i', i', for the gauges are provided.

The basin v'' is crossed in the middle by an iron platform, which for the convenience of the service is made moveable on rails, to both ends of the basin.

A basin v''', larger than the preceding, having a length of 20 metres and a width of 10 metres and a horizontal bed, is intended to still the waves and the whirlpools produced by the fall of the water from the "Modellatrice" overfall. It can feed the experimental basin B, which is on the prolongation of the same longitudinal axis of the basin and the lateral basin of feeding v^{iv}.

Lateral Basin for the Discharges of 300 litres.—The basin v^{iv}, is for experimenting on discharges not exceeding 300 litres, the most convenient discharges for all varied researches of hydraulics.

The feeding basin v^{iv} is 5 metres wide and 21·601 long. For destroying even the smallest of its movements the water, which has a depth of 1·30 metres, is made to descend into a well p as wide as the basin itself, 4 metres long and 1 metre deep and divided at mid-length by a cross moveable diaphragm having the form of a gate and thus can be immersed in the well in case of need.

We have thus, in this basin v^{iv}, an absolutely still water surface. At the head of the basin b the exparimental sluices can be placed.

The experimental basin b is 3 metres wide and 20·68 long. Its horizontal bed is 1·70 metres lower than that of the feeding basin v^{iv}, which makes the flowing always free. In the middle of its length the basin b has a well p' provided with a diaphragm for stilling the waves produced by the drop already mentioned.

According to circumstances the sluices of proofs can be placed at one or the other end of the basin. The upper end has the sluice divided into two parts by a pier in the middle and is surmounted by a bridge, formed of two blocks of stone, for manipulation. But at the other end it is possible to apply sluices up to the total width of 3 metres. Leaving the upper end free, a maximum depth of water of 3 metres on the lower edge of the sluice can be obtained at the lower end. At the two

ends of the basin, on the left side, two hydrometrical wells are placed, both divided into two compartments, for measuring the height of the water immediately above the sluices and at the point at which the liquid remains stagnant.

"*Apri-Serra*" *of the Engineer Colli.*—From the basin b the water flows on to the canal c' whose bed is also 1·70 metres below the floor of the preceding basin. This canal c' is closed at its lower end and presents on its bed at (a) two rectangular grooves, parallel and of equal size, 1·75 metres long (in the direction of the axis of the canal), and 0·20 metre wide. From the left groove the water flows into a lower canal which conveys it to be measured in the left basin m. From that on the right the water precipitates into the escape channel s. The size of these grooves is such that even when disposing of only 2·20 metres of water above the bed of the canal, they can always escape a discharge of 350 litres per second without giving place to swelling. On each groove runs a wooden cover 0·10 metre longer and larger than the groove itself, and the two covers are joined together by means of a frame running on four wheels and commanded by a lever. When one of the grooves is closed the other opens simultaneously. Fig. 4 is a longitudinal section and Fig. 5 a cross-section on a larger scale of the "Apri-Serra" above described. The system is very simple, and was invented by one of the members of the Commission, the Engineer Rocco Colli. It is intended for experiments on small discharges varying from 100 to 200 litres.

At right angles there starts from the basin v^{iv}, the canal c, 1·40 metres wide having a horizontal bed at the same level as the basin v^{iv} for a distance of 40 metres, after which a drop of 1·42 metres takes place. Besides the use of this canal for the care of the Rheometers, it is also destined essentially to ascertain the influence produced on the discharge of a head sluice of given size by a canal that follows this head sluice. For this purpose the sluice o or the sluice o'can be used and the water can be escaped through them into the small measuring basin m, or through the canal $c''m$ into the large measuring basin M. The canal d which follows the sluice o, is 1·00 metre long (see Fig. 4); it presents a sudden drop of 1·13 metres. With this arrangement, it will be possible to ascertain the influence that the current in the canal c has on an open sluice in its side.

Discharging Tower.—On the right side of the canal c is placed the sluice o' which conducts the water into the discharging tower, intended for small experiments. This tower indicated on the plan at t and reproduced on a larger scale in Fig. 7, which gives a vertical section through

the axis, is a basin 3·20 metres long and 2 metres wide. It is divided inside into two parts, the first part of 1·50 metres presents a drop of 1·95 metres from the bed of the feeding canal and the remaining part of 1·70 metres ensures a total drop of 4 metres.

In the side of this tower and facing the measuring basin, four square openings, of 0·60 metres are made and placed one above the other or at a distance of 1·45 metres from centre to centre. The lowest opening has its lower lip 4 metres below the sill of the feeding sluice and by regulating the height of the water in the canal, it will be possible to measure discharges under heads varying from zero to 5·30 metres. A cast iron plate keeps the openings which are not being experimented upon closed, and a slide of iron or brass in which the size of the opening to be experimented on is cut will be used at time of experiment only. The working of both plate and slide is affected by a system of rollers, chain and crane. A moveable platform assists in making the manipulation easy. The openings of the tower can be reduced in size by different slides to 0·20 metres by 0·20 metres.

For emptying the tower when the experiment is over, there is a hole in its bed of 0·15 metre diameter, closed by cover which is worked by a crank. From this emptying hole starts a cast iron pipe 0·15 metre diameter joined to the escaping pipe e' of the measuring basin.

Large Experimental Basin.—For making experiments on middle discharges of 3 cubic metres per second, the experimental basin B, 5 metres wide and 35 metres long, is placed in continuation of the feeding basin v'''.

At the beginning of this basin there is a well p'' similar to the wells p, p', already described. At a distance of 10 metres from the origin of this basin the first sluices of proofs can be placed, and for this purpose the width of the basin is divided into three parts by two piers of 0·40 metre each, on which are placed the blocks of the service bridge. The horizontal bed of this first part of the basin is at the same level as that of the feeding basin v'''. After a drop of 1·40 metres the second part of the basin, 25 metres long, is divided at the middle at the place of the well p'' by a diaphragm for stilling the water. At the other end of the basin where the width is not divided by piers, sluices of greater width than that of the upper part can be experimented on. Here the service bridge is an iron foot-bridge.

Against the sluice placed at the upper end of the above described basin a depth of 1·30 metre of water can be got over the lower lip of these sluices, and by removing these sluices a depth of 2·70 metres of water can be obtained against the sluices placed at the lower end of the same basin.

By these last sluices the water escapes, after a drop of 1·42 metres, into the canal c' which directs it by means of the "Apri-Serra" A, into the escaping channel s' or into the the measuring basin M, as will be seen further on.

Finally, it is to be noted that the basin B is provided on the right side with two hydrometrical wells with double compartments for the same purpose as those previously mentioned.

Lateral Basin.—Another experimental basin B′ receives the water directly from the great derivator, with a drop of 1·10 metres. It is 3 metres wide and 24 metres long, divided by a diaphragm into two parts at the usual well p^{iv} for settling the water which flows from the sluice placed on the side of the canal c. At the lower extremity other sluices can be placed for discharging the water into the canal c' placed above the "Apri-Serra" A, thence into this "Apri-Serra" and finally into the measuring-basin M. But as the discharges here are not considerable it is better to resort for their measuring to the small measuring basin m. This basin is essentially meant for solving the important problem of finding the difference which exists between the head of water on a sluice open in the side of a canal, the water of which has a certain velocity, and the corresponding head in the case of the upstream water being still. It is evident that in experimenting on the side of the canal c, as well as on the end of the basin B′, with sluices situated under the same conditions of flow after the establishment of the uniform movement, the two sluices will give the same discharge and by the reading of the hydrometers the difference in head sought for will be known.

For this purpose there are in the sides of the canal c two hydrometres, one to give the level immediately above the sluice and the other to give the level against the opposite side of the canal in front of the sluice. Moreover, there are for the sluice at the lower end of the basin two hydrometres to ascertain the height of the water immediately above the sluice and at the point where the water is known to be most stagnant.

At the two ends of the basin where the sluices are placed, there is a pier in the middle on which the blocks forming the service bridge are placed.

"Apri-Serra" for Middle Discharges.—For the discharge not exceeding 3 cubic metres per second a system of "Apri-Serra" is used in order to be able to close almost suddenly the access of water. This "Apri-Serra" is provided with two doors (Fig. 6) one is comparatively light as it is of wood, while the other is of cast iron and consequently

heavy. Both are fixed to a side lever so that when the heavier door, which is kept up with hooks and a spring, is let free it falls by virtue of its own weight and the wooden door is raised at the same time.

It is absolutely necessary in employing this apparatus to provide two sets of heavy and light doors inversely placed. The arrangement adopted is clearly shown on the general plan. It will be seen that at the end of the canal c' the water passes into a basin divided into two sluices by a water-cutter. From the right sluice the water falls into the escape channel s' and from the left sluice it goes into the basin A which is in its turn divided into two sluices, one conveying the water into the measuring-basin and the other to the escape channel s'. The sluice that conveys the water to the escape channel of the first two sluices is provided with a cast iron door while the other is provided with a wooden door. Of the second two sluices the one that conveys the water to the measuring basin is that provided with the heavy door. As there is no overflow, the four sluices are made each 2·10 metres wide.

Before commencing the experiment the two cast iron doors are raised together and the water let flow into the escape channel. The fall of the first cast iron door indicates the beginning of the experiment and causes the water to enter the measuring-basin, while the fall of the second iron door causes the water to pass into the escape channel and indicates the end of the experiment. The doors are 1·00 metre high, those of cast iron are 0·04 metre thick and weigh 600 kilogrammes each.

The cast iron doors are raised by means of hand screw-jack and lowered by a spring and a lever. The lower part of the doors is fitted with felt for rendering the closure tight and reducing the effect of the shock produced by their fall on the sill.

"*Apri-Serra*" *for big Discharges.*—The canal cc, which is 6 metres wide and has a slope of 0·0005 metre per metre, meets at a distance of 86·50 metres from its origin after the last basin, the great "Apri-Serra" B, represented by a longitudinal and cross-sections on Fig. 2 and 3. From these figures it is apparent that the three openings π which allow the water to go down into the measuring basin M by means of a covered canal q are placed on the same vertical, under the openings which lead the water to the escape channel s.

The three upper openings being considered as weirs with no contraction on the bottom (cœfficient$=0·403$), and having 1·70 metre depth of water on their sill, require for discharging the quantity of 12 cubic metres per second a total width of 3·03 metres. Each opening has effectively a width of 1·02 metres. The three lower openings have

the same width and a height of 0·90 metre and their centre is 1·05 metres below the bottom of the canal, and consequently they have a head of 2·75 metres. Adopting for cœfficient 0·65, the contraction being nil, the discharge of each opening will be 4·20 cubic metres.

For each of the three openings there is a door composed of a frame of iron with two platforms, leaving between them a space 2·25 metres high. The lower platform is of wood and is 1·10 metres high, the upper one is of cast iron and is 1·85 metres high.

Raised to their maximum height the three doors, with the lower platform, close the three openings π while the upper openings remain fully open and the water of the canal *c* goes into the escape channel. Letting the entire frames fall and strike against the bottom of the "Apri-Serra" the openings π open and the upper ones are closed by the upper platform and the water of the canal *c* goes to the measuring-basin.

The upper platform, which is of cast iron, slides in the iron frame. Immediately a retention nail is removed, this platform goes down, strikes against the lower platform, closes the openings π, and causes the water to go anew into the escape channel.

Nails of retention and springs well studied in all their particulars permit the two manœuvres of falling to be very easily made; first by the lowering of the entire frame by sliding it in the cast iron grooves of piers, and second by the lowering of the upper platform along the frame. On the bottom *h* wooden beams are placed for weakening the shock, and the lower extremity of the cast iron platform is provided with a coat of felt.

At the distance of 4·40 metres above the doors of the "Apri-Serra" other doors are placed, worked with screws for the purpose of intercepting the passage of water in one or two of the openings.

Measuring Basins.—On account of the great variety of discharges to be experimented on in the station, a single measuring-basin would be too small for some discharges and too large for others, and for this reason two basins were provided.

The smaller basin *m* is 8 metres long, 7 metres wide and 2 metres deep; taking into account the admission canal under the "Apri-Serra" (*a*), this basin would present a capacity of 117 cubic metres; but the entire height of this basin cannot be utilized on account of the perturbations produced on the water surface. To every millimetre in the height corresponds a volume of about 58½ litres, and in experimenting with the maximum discharge of 300 litres per second, the water rises 0·005 metres in the basin every second and the experiment can last for 400 seconds or 6 minutes 40 seconds.

The larger basin M is 30 metres long, 20 metres wide and 3 metres deep. If the canals of admission of the middle and of the large "Apri-Serra" are included, this basin will have a capacity of 1,916 cubic metres, and to every millimeter of height corresponds a volume of 628 litres. In experimenting with the maximum discharge of 3 cubic metres per second, there will be a rise of level of 5 millimetres per second and the experiment can last for 600 seconds or 10 minutes.

In experimenting with the maximum discharge of 12 cubic metres per second the level of water in the basin rises 20 millimetres every second and the experiment can last for 150 seconds.

In each basin there is placed laterally a waste weir (F and *f*) which communicates with the escape channel (*s* and *s'*) in case it is desired to experiment with the basin full.

The small basin is emptied by means of a pipe *c*, 45 millimetres diameter which joins the general escape and requires 5 minutes to entirely empty the basin. The pipe is closed by a cover worked by a screw.

The large basin is also emptied by means of a pipe E, 850 millimetres diameter, and needs 15 minutes for emptying entirely. Such interval is precisely that necessary for putting the doors of the "Apri-Serra" in place.

Chrono-Hydrometrograph of M. Salmoiraghi.—Two small buildings (G and *g*) close by the measuring-basins, have an internal surface of 3 metres square and in them are kept the Hydrometrographs. These instruments were invented by M. Salmioraghi and by means of them he promises to obtain at any moment the water levels in the measuring-basins, and the time employed for reaching any water level.

As the discharges of 10 to 12 cubic metres raises the level about 20 milimetres per second in the measuring-basin, it would not be sufficient for ascertaining the smallest variations in the water levels to trust the hydrometres, since it is necessary also to ascertain the time employed for reaching any level.

M. Salmoiraghi fixes his instruments in the well in such a manner that the float gives the moving impulse to a strip of paper, which develops itself proportionally to the height that the water reaches in the well. A pen inscribes on this paper the seconds. For this purpose he uses an electro-magnet under command of a seconds pendulum. All this supposes, of course, the possibility of preventing altogether the oscillation of the water surface in the well.

Escape Channel.—After the large "Apri-Serra" the general escape channel *s* runs in earth and escapes the water which serves in the

experiments into the Ivrea Canal and thence into the Cavour Canal, and thus this water is not lost.

Buildings.—A small house H, 14 metres by 14 metres, with a ground floor and an upper storey, afford the necessary rooms for the direction, the guard and the collection. On the ground floor there is a room for the audiences, a room for the collection of the instruments and two rooms for storing materials. In the upper storey there is the reading room of the director and the lodging of the guard.

A shelter K, 6 metres by 10 metres, is intended also for storing materials.

As this station was not yet used for experiments on my visit to it in September, 1899, I could not collect any information about the practical results which it is meant to give.